DIAGNOSTICS FOR E-P INSTABILITY OBSERVATION

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Motivation

- For verification of computer codes for instability simulation it is important to have a reliable experimental date in simple conditions.
- Experiments in small scale low energy rings can be used for quantitative verification of simulation codes and for development of methods for instability damping .
- Informative diagnostics is important for collection of necessary information.

Outline

- e-p instability: historical remarks and references
- Small scale Proton Storage Rings
- Diagnostics
- Observations
- Damping of e-p instability and production of a stable space charge compensated circulating beam with high intensity

Abstract

- Diagnostics for observation and identification of instabilities driving by interaction with secondary plasma in small scale PSR are considered.
- Clearing electrodes, fast gauges, fast valves,fast extractors, repulsing electrodes, electron and ion collectors with retarding grids, particles spectrometers using for detection of secondary particles generation and secondary particles identification will be discussed. Features of electrostatic and magnetic dipole and quadrupole pickups will be presented. An influence of nonlinear generation of secondary plasma in driving and stabilization of e-p instability is discussed. Observations of anomaly in secondary particles generation will be presented.

Two-stream instability, historical remarks

- Beam instability due to electrons were first observed with coasting proton beam and long proton bunches at the Novosibirsk INP(1965), the CERN ISR(1971), and the Los Alamos PSR(1986)..
- Recently two-stream instability was observed in almost all storage rings with high beam intensity.
- Observation of two-stream instability in different conditions will be reviewed. Diagnostics and damping of two-stream instability will be discussed

Two-stream instability

- Beam interaction with elements of accelerator and secondary plasma can be the reason for instabilities, causing limited beam performance.
- Improving of vacuum chamber design and reducing of impedance by orders of magnitude relative with earlier accelerators increases threshold intensity for impedance instability.
- Two-stream effects (beam interaction with a secondary plasma) become a new limitation on the beam intensity and brightness. Electron and Antiproton beams are perturbed by accumulated positive ions. Proton and positron beams may be affected by electrons or negative ions generated by the beam. These secondary particles can induce very fast and strong instabilities. These instabilities become more severe in accelerators and storage rings operating with high current and small bunch spacing

This instability is a problem for heavy ion inertial fusion, but ion beam with higher current density can be more stable.

Instability can be a reason of fast pressure rise include electron stimulated gas desorption, ion desorption, and beam loss/halo scraping. Beam induced pressure rise had limited beam intensity in CERN ISR and LEAR. Currently, it is a limiting factor in RHIC, AGS Booster, and GSI SIS. It is a relevant issue at SPS, LANL PSR, and B-factories. For projects under construction and planning, such as SNS, LHC, LEIR, GSI upgrade, and heavy ion inertial fusion, it is also of concern.

Budker Institute of Nuclear Physics

www.inp.nsk.su

First project of proton/antiproton collider VAPP, in the Novosibirsk INP (BINP), 1960

- Development of charge-exchange injection (and negative ion sources) for high brightness proton beam production. First observation of e-p instability.
- Development of Proton/ Antiproton converter.
- Development of electron cooling for high brightness antiproton beam production.
- Production of space charge neutralized proton beam with intensity above space charge limit. Inductance Linac, Inertial Fusion, Neutron Generators.

References

www.google.com two-stream transverse instability…

For more information see the website for the
8th ICFA Mini Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings, Santa Fe, NM Feb 16-18, 2000
http://www.aps.anl.gov/conferences/icfa/two-stream.html

Also see the website for the
International Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings, KEK Tsukuba, Japan, Sept 11-14, 2001
http://conference.kek.jp/two-stream/

http://wwwslap.cern.ch/collective/electron-cloud/.

Historical remark

Electron cloud effects (ECEs) were first observed 38 yrs ago in small, medium-energy proton storage rings. These were described as: Vacuum pressure bump instability, beam-induced multipacting, and/or e-p instability:

> **BINP Proton Storage Ring** [G. Budker, G. Dimov, and V. Dudnikov (1966); see also review by V. Dudnikov (2001)] v.dudnikov.ph.D.thesis,1966
>
> **CERN Intersecting Storage Ring (ISR)** [O. Grobner (1977)]

First observation in a positron ring around 1995: Transverse coupled-bunch instability in e+ ring only and not in e- ring:

> **KEK Photon Factory (PF)** [M. Izawa, Y. Sato, T. Toyomasu (1995) and K. Ohmi, (1995)]
>
> **IHEP Beijing e+/e- collider (BEPC)**: experiments repeated and KEK PF results verified [Z.Y. Guo et al. (1997)]

References for first observation of e-p instability

- V.Dudnikov, Ph.D.Thesis, The intense proton beam accumulation in storage ring by charge-exchange injection method", Novosibirsk INP,1966.
- G. Budker, G. Dimov, V. Dudnikov, "Experiments on production of intense proton beam by charge exchange injection method" in Proceedings of International Symposium on Electron and Positron Storage Ring, France,Sakley,1966, rep. VIII, 6.1 (1966).
- G. Budker, G. Dimov, V. Dudnikov, "Experimental investigation of the intense proton beam accumulation in storage ring by charge- exchange injection method", Soviet Atomic Energy, 22, 384 (1967).
- G.Budker, G.Dimov, V. Dudnikov, V. Shamovsky, "Experiments on electron compensation of proton beam in ring accelerator", Proc.VI Intern. Conf. On High energy accelerators, 1967, MIT & HU,A-104, CEAL-2000, (1967).
- G.I.Dimov, V.G.Dudnikov,V.G.Shamovsky, " Transverse instability of a proton beam due to coherent interaction with a plasma in a circular accelerator" Soviet Conference on Charge-particle accelerators",Moscow,1968, translation from Russia, 1 1973 108565 8.
- G. Dimov, V. Dudnikov, V. Shamovsky, "Investigation of the secondary charged particles influence on the proton beam dynamic in betatron mode ", Soviet Atomic Energy, 29,353 (1969).
- Yu.Belchenko, G.Budker, G.Dimov, V.Dudnikov, et al. X PAC,1977.
- O.Grobner, X PAC,1977.
- E. Colton, D. Nuffer, G. Swain, R.Macek, et al., Particle Accelerators, 23,133 (1988).

Models of two-stream instability

- The beam- induces electron cloud buildup and development of two-stream e-p instability is one of major concern for all projects with high beam intensity and brightness [1,2].
- In the discussing models of e-p instability, transverse beam oscillations is excited by relative coherent oscillation of beam particles (protons, ions, electrons) and compensating particles (electrons,ions) [3,4,5].
- For instability a bounce frequency of electron's oscillation in potential of proton's beam should be close to any mode of betatron frequency of beam in the laboratory frame.

1. http://wwwslap.cern.ch/collective/electron-cloud/.
2. http://conference.kek.jp/two-stream/.
3. G.I.Budker, Sov.Atomic Energy, 5,9,(1956).
4. B.V. Chirikov, Sov.Atomic.Energy,19(3),239,(1965).
5. M.Giovannozzi, E.Metral, G.Metral, G.Rumolo,and F. Zimmerman , Phys.Rev. ST-Accel. Beams,**6**,010101,(2003).

Development of Charge Exchange Injection and Production of Circulating Beam with Intensity Greater than Space Charge Limit

V.Dudnikov. "Production of an intense proton beam in storage ring by a charge- exchange injection method", Novosibirsk, Ph.D.Thesis,INP, 1966.

Development of a Charge- Exchange Injection; Accumulation of proton beam up to space charge limit; Observation and damping of synchrotron oscillation; Observation and damping of the coherent transverse instability of the bunched beam. Observation of the e-p instability of coasting beam in storage ring

G. Budker, G. Dimov, V. Dudnikov, "Experiments on production of intense proton beam by charge exchange injection method" in Proceedings of International Symposium on Electron and Positron Storage Ring, France,Sakley,1966, rep. VIII, 6.1 (1966).

G. Budker, G. Dimov, V. Dudnikov, "Experimental investigation of the intense proton beam accumulation in storage ring by charge- exchange injection method", Soviet Atomic Energy, 22, 384 (1967).

G.Dimov, V.Dudnikov, "Determination of circulating proton current and current density distribution (residual gas ionization profile monotor)", Instrum. Experimental Techniques, 5, 15 (1967).

Dimov. "Charge- exchange injection of protons into accelerators and storage rings", Novosibirsk, INP, 1968.

Development of a Charge- Exchange Injection; Accumulation of a proton beam up to the space charge limit; Observation and damping of synchrotron oscillations; Observation and damping of the coherent transverse instability of the bunched beam;.

Shamovsky. "Investigation of the Interaction of the circulating proton beam with a residual gas", Novosibirsk, INP, 1972.

Observation of transverse e-p coherent instability of the coasting beam in the storage ring, Observation of a transverse Herward's instability, Damping of instabilities, Accumulation of a proton beam with a space charge limit.

G. Dimov, V. Dudnikov, V. Shamovsky, "Transverse instability of the proton beam induced by coherent interaction with plasma in cyclic accelerators", Trudy Vsesousnogo soveschaniya po uskoritelyam, Moskva, 1968, v. 2, 258 (1969).

G. Dimov, V. Dudnikov, V. Shamovsky, "Investigation of the secondary charged particles influence on the proton beam dynamic in betatron mode ", Soviet Atomic Energy, 29,353 (1969).

G.Budker, G.Dimov, V. Dudnikov, V. Shamovsky, "Experiments on electron compensation of proton beam in ring accelerator", Proc.VI Intern. Conf. On High energy accelerators, 1967, MIT & HU,A-104, CEAL-2000, (1967).

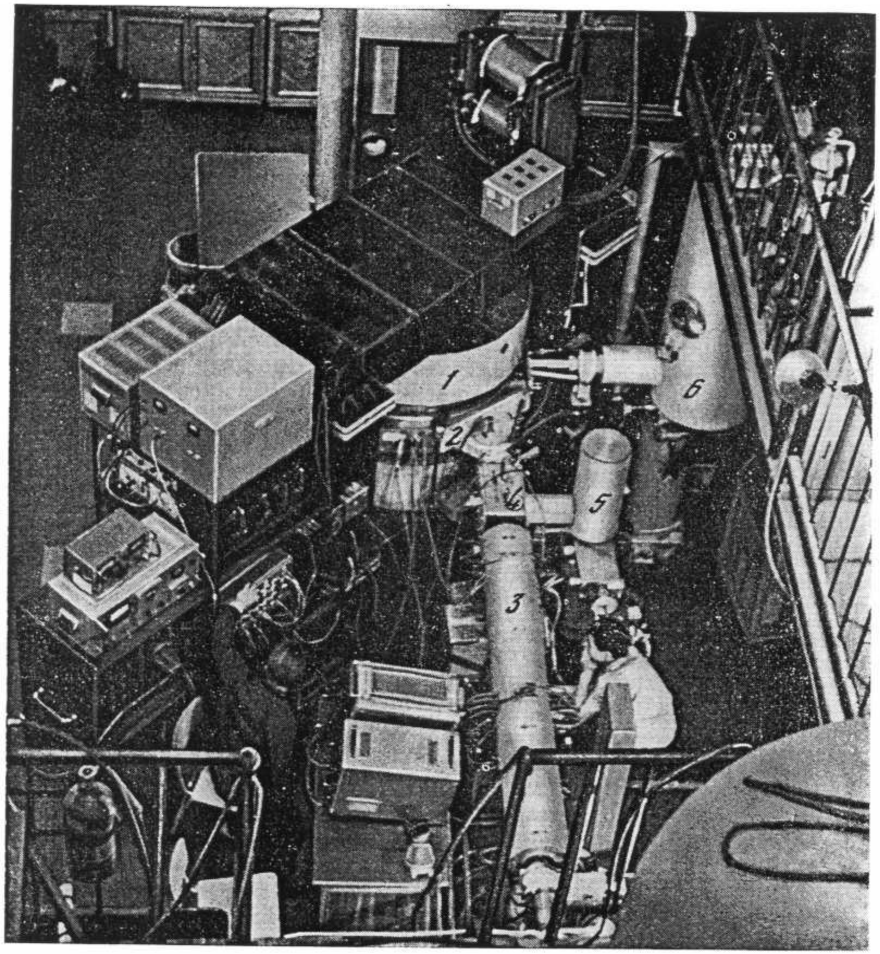
Chupriyanov. "Production of intense compensated proton beam in an accelerating ring", Novosibirsk, INP, 1982.

Observation and damping transverse coherent e-p instability of coasting proton beam and production of the proton beam with an intensity up to 9.2 time above a space charge limit.

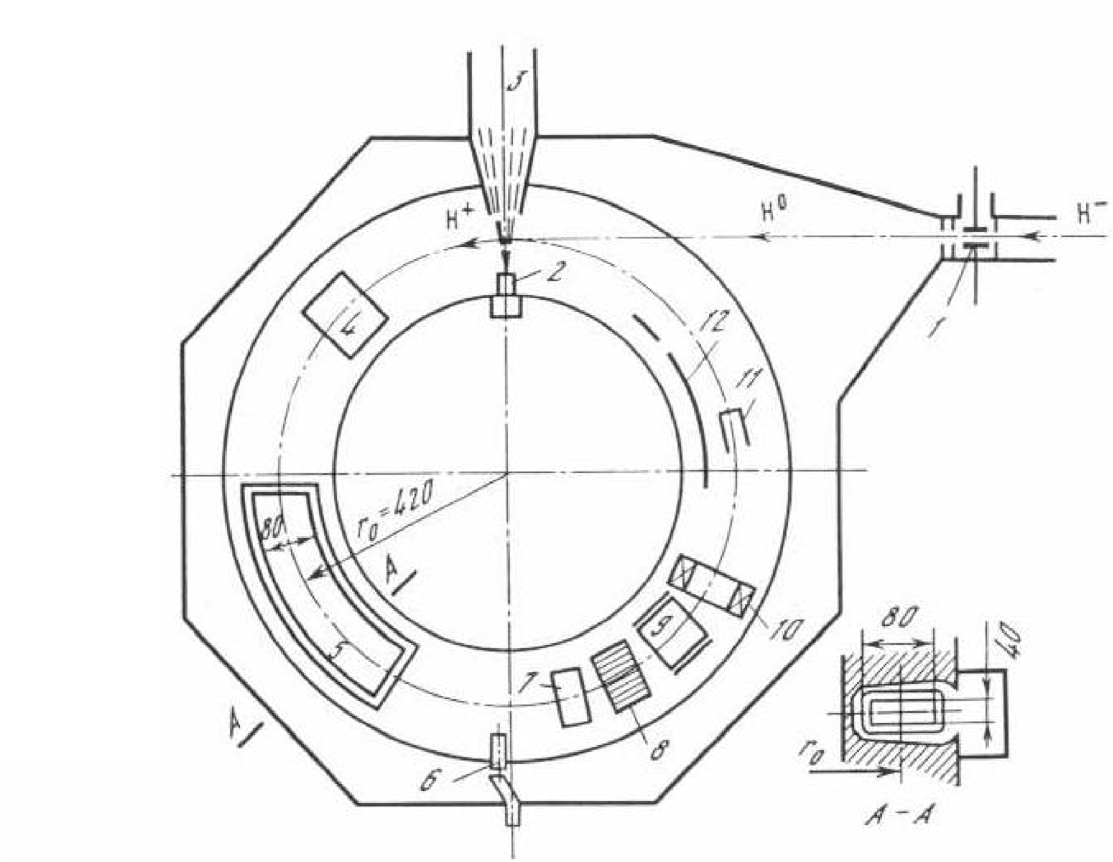
G.Dimov, V.Chupriyanov, "Compensated proton beam production in an accelerating ring at a current above the space charge limit",

Particle accelerators, 14, 155- 184 (1984). Yu.Belchenko, G.Budker, G.Dimov, V.Dudnikov, et al.X PAC,1977.

General view of INP PSR with charge exchange injection 1965



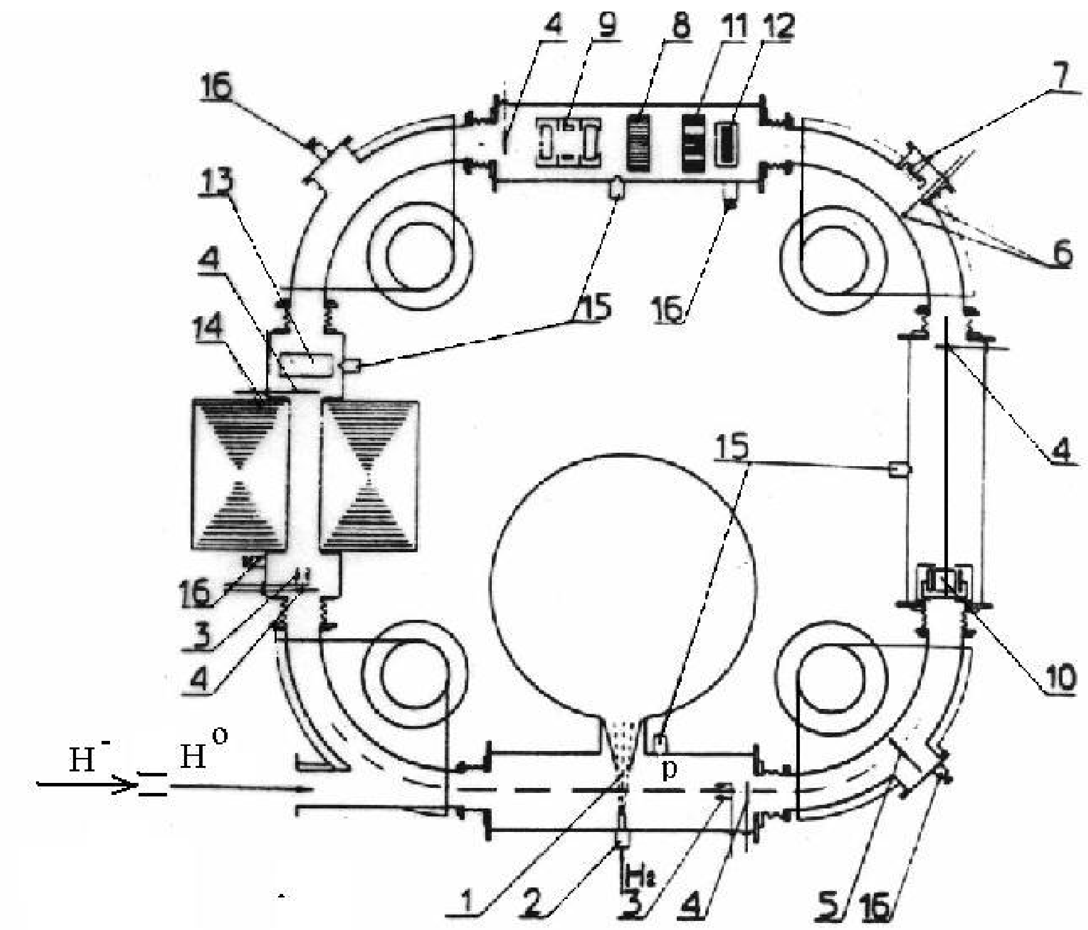
INP PSR for bunched beam accumulation by charge exchange injection



1- Fist stripper; 2-main stripper Pulsed supersonic jet; 3-gas pumping;
4-pickup integral;
5- accelerating drift tube;
6-gas luminescent profile Monitor; 7-Residual gas current monitor;8-residual gas IPM; 9-BPM;
10-transformer Current monitor; 11-FC;
12- deflector for Suppression transverse instability by negative Feedback.

Small Radius- High beam density. Revolution 5.3 MHz. 1MeV, 0.5 mA, 1 ms.

PSR for Circulating p-Beam Production



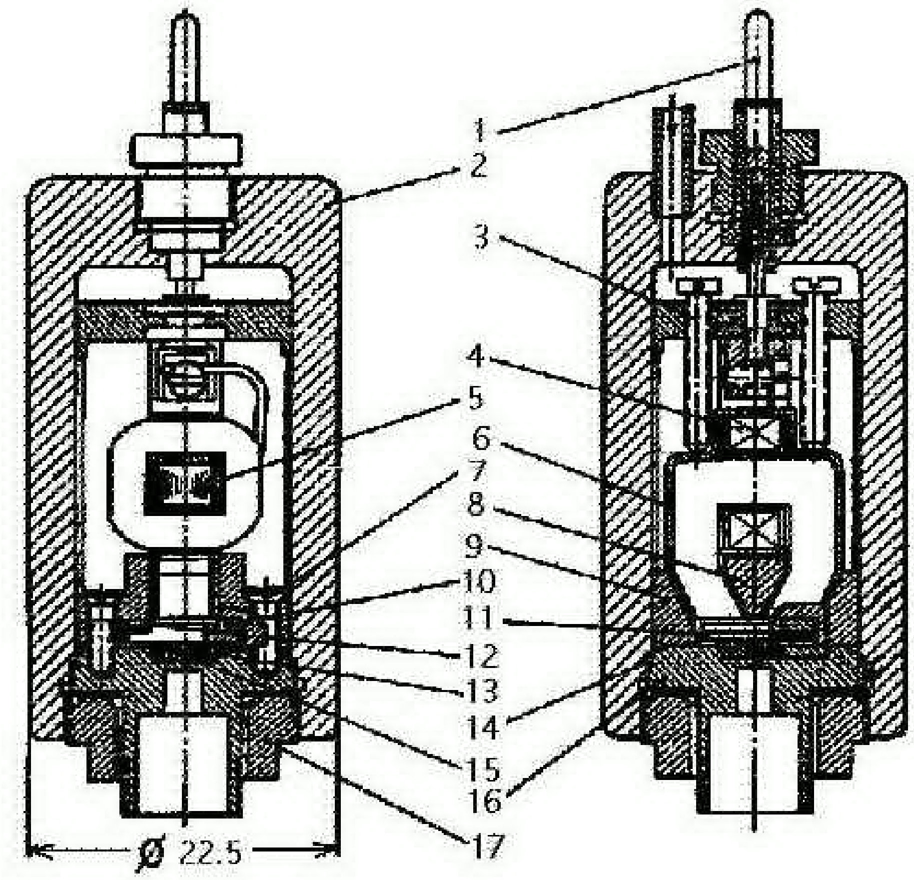
1-striping gas target; 2-gas pulser;3-FC; 4-Q screen; 5,6-moving targets; 7-ion collectors; 8-current monitor; 9-BPM;10-Q pick ups; 11-magnetic BPM; 12-beam loss monitor;13-detector of secondary particles density; 14-inductor core; 15-gas pulsers; 16-gas leaks.

Proton Energy -1 MeV; injection-up to 8 mA; bending radius-42 cm; magnetic field-3.5 kG;index-n=0.2-0.7; St. sections-106 cm;aperture-4x6 cm; revolution-1.86 MHz; circulating current up to 300mA is up to 9 time greater than a space charge limit.

Vacuum control

- Stripping target- high dense supersonic hydrogen jet (density up to e19 mol/cm^3, target e17 mol/cm^2 , ~1ms)
- Vacuum e-5 Torr
- Fast, open ion gauges
- Fast compact gas valves, opening of 0.1 ms.

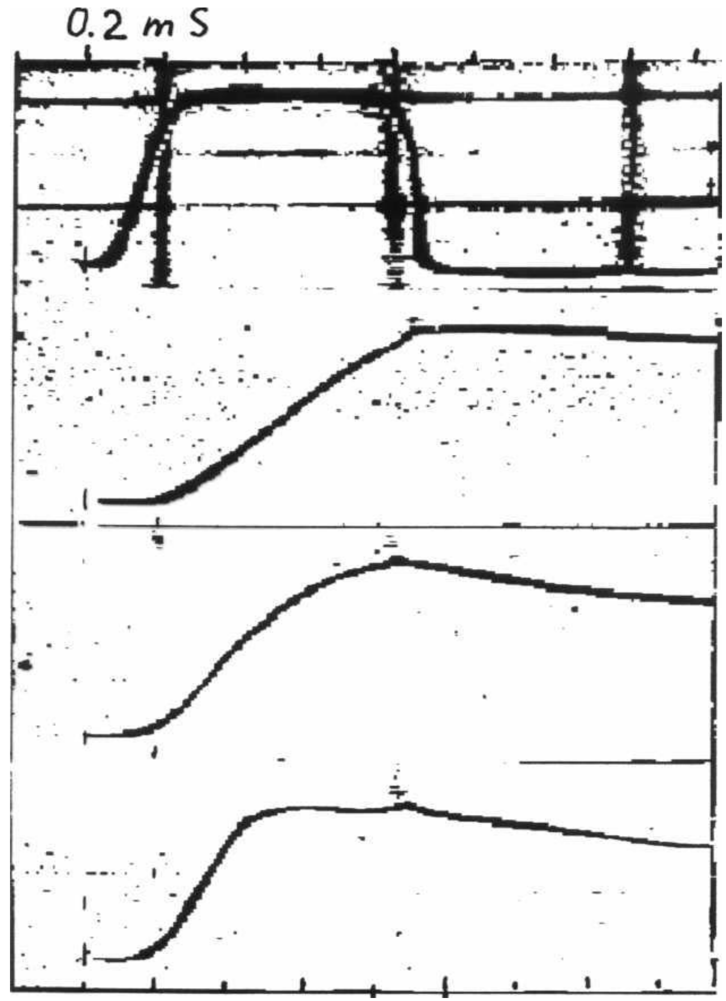
Fast, compact gas valve, 0.1ms, 0.8 kHz



1 -current feedthrough; 2 housing; 3-clamping screw; 4-coil; 5 magnet core; 6-shield; 7-screw; 8-copper insert; 9-yoke; 10-rubber washer-returning springs; 11-ferromagnetic plate-armature; 12-viton stop; 13-viton seal; 14-sealing ring; 15-aperture; 16-base; 17-nut.

Photograph of a fast, compact gas valve

Proton beam accumulation for different injection current (0.1-0.5 mA)



Injected beam

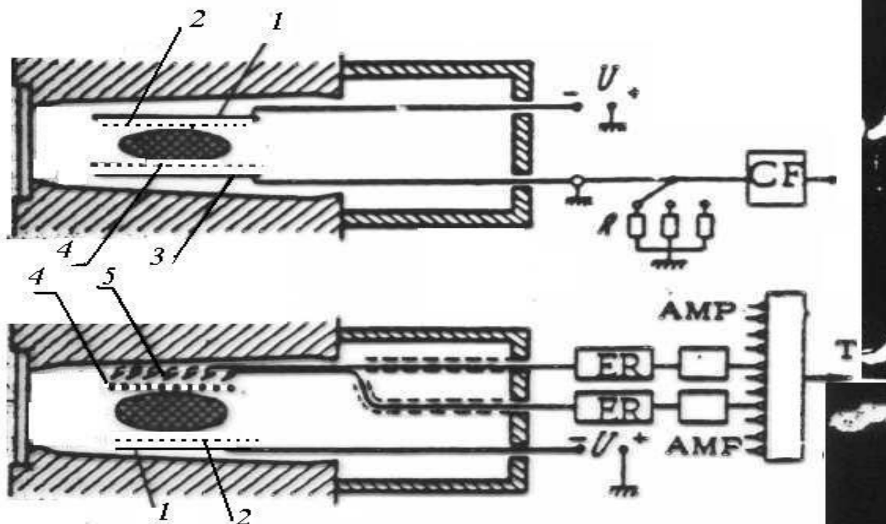
Circulating beam,

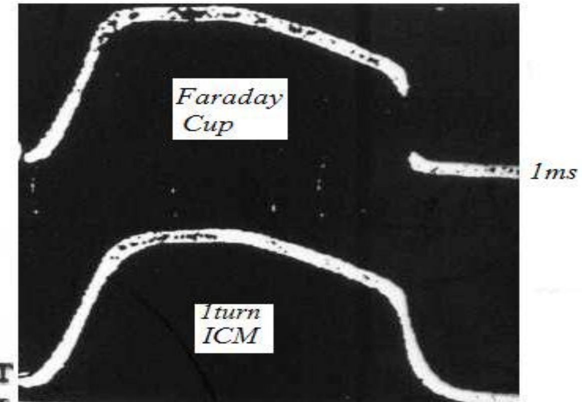
Low injection current

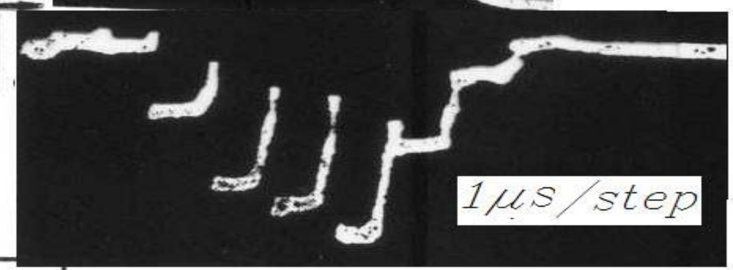
Start saturation

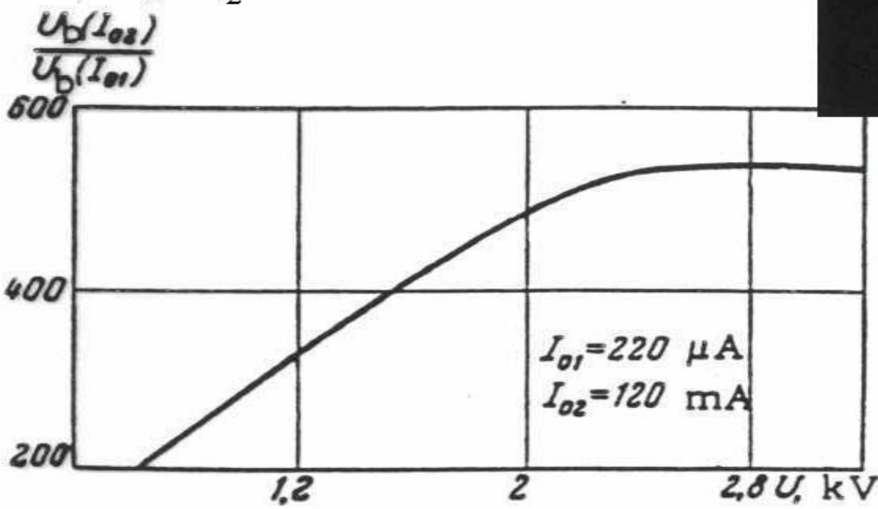
Strong saturation

Residual gas ionization beam current & profile monitors (ICM,IPM),1965.









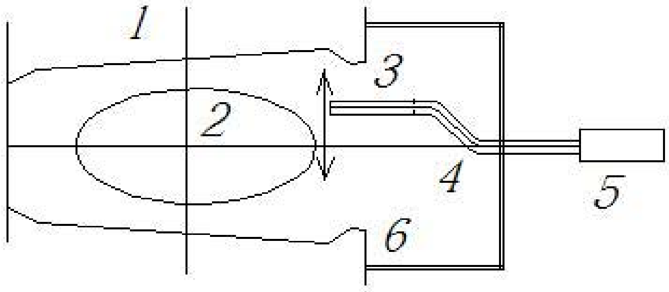
Residual gas IPM.V.Dudnikov,1965.

1-reflection platre;2-suppression grid;

3-collector plate;4-shilding grid;

5 collector strips.

Residual gas luminescent beam profile monitor, INP,1965



1- magnetic pole;

2- proton beam;

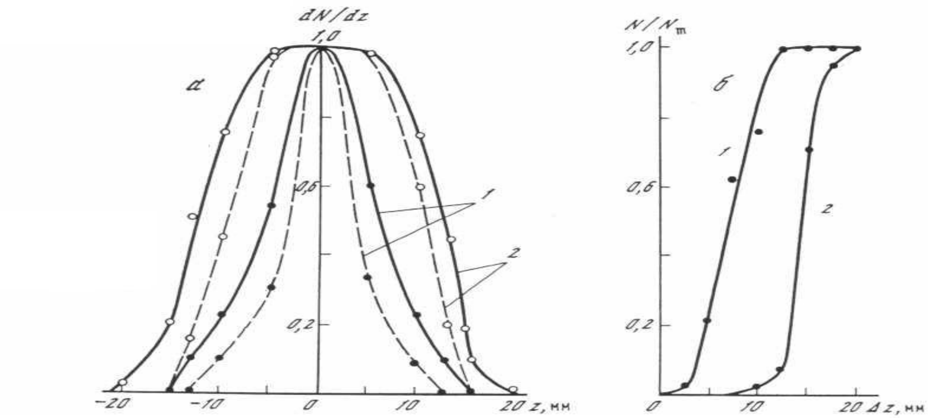
3- moving collimator

4- light guide;

5-photomultiplier;

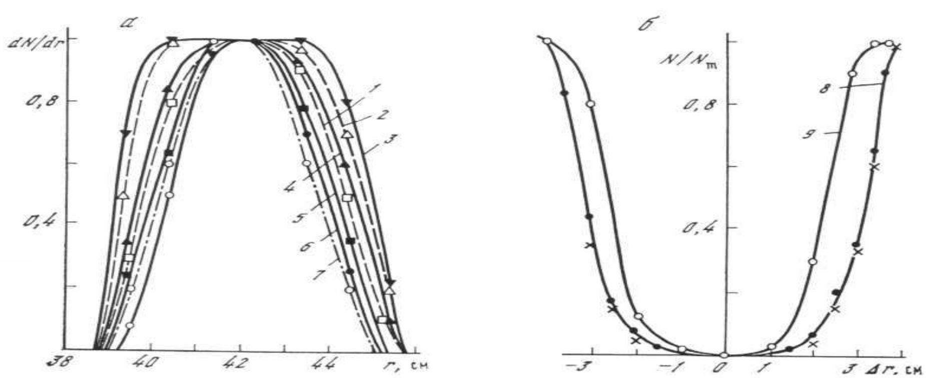
6-vacuum chamber

Beam profiles evolution during accumulation



Residual gas luminescent beam profilometer signa, and beam intensity vs vertical aperture

а — $N_m = 2\cdot10^{11}$; б — $N_m = (2 \div 20)\cdot10^{10}$; 1 — $\alpha_z = 0$; 2 — $\alpha_z = 0{,}12$



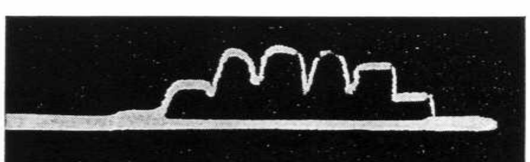
Residual gas ionization beam profile monitor (IPM) signal and beam intensity vs radial aperture

1 — 6: $N_m = 2{,}5\cdot10^{11}$, t = 1600 мкс (1); 900(2); 700(3); 400(4); 200(5); 50(6); 7 — $N_m = 5\cdot10^{10}$, t = 200 ÷ 2000 мкс; 8 — $N_m = 2{,}6\cdot10^{11}$; 9 — $5\cdot10^{10}$

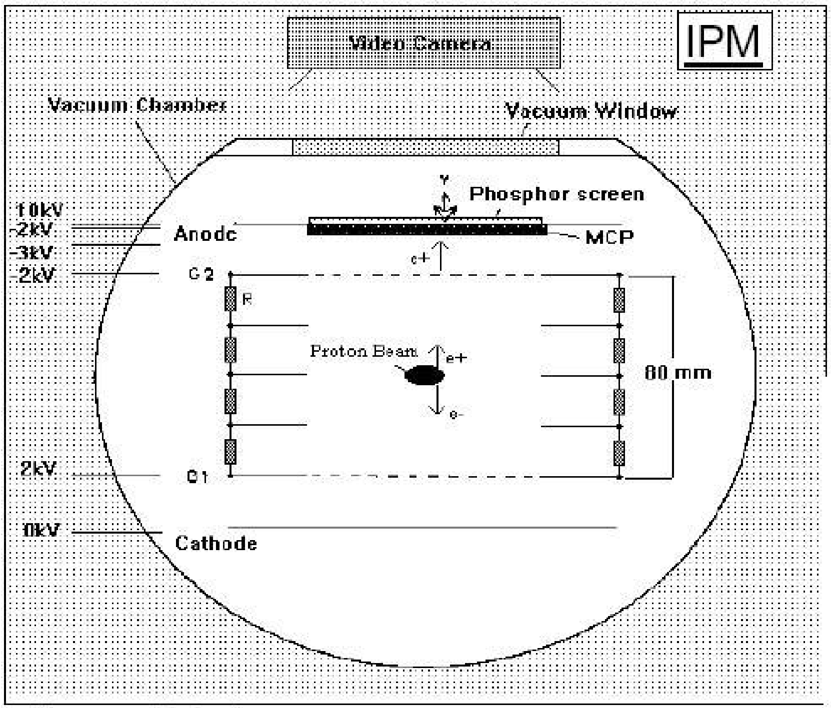
IPM signal, electron collection in B field

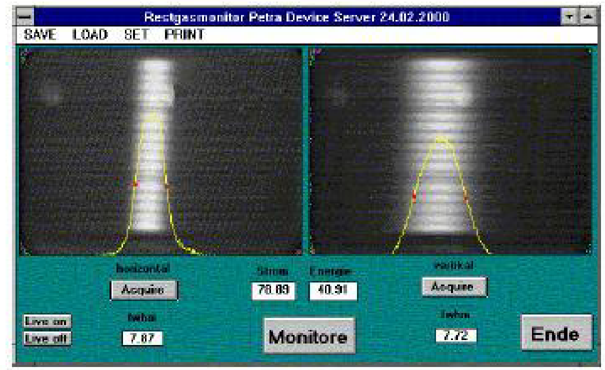
Step 9mm.

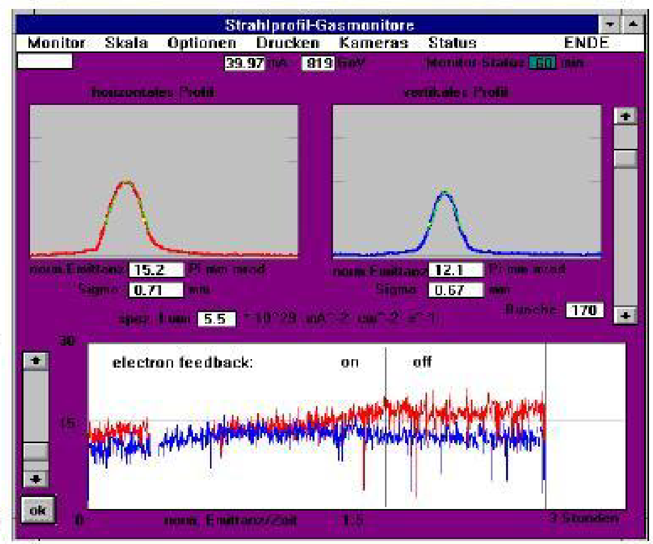
V.Dudnikov, 1965,



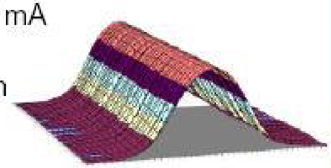
Modern IPM (DESY)







- »Vacuum 10-9 mbar
- »1 - 60 - 210 Bunches => << 0.1 - 160 mA
- »7.5 - 40 - 820 GeV/c
- »beam width << 1 mm, length 30 - 3 cm

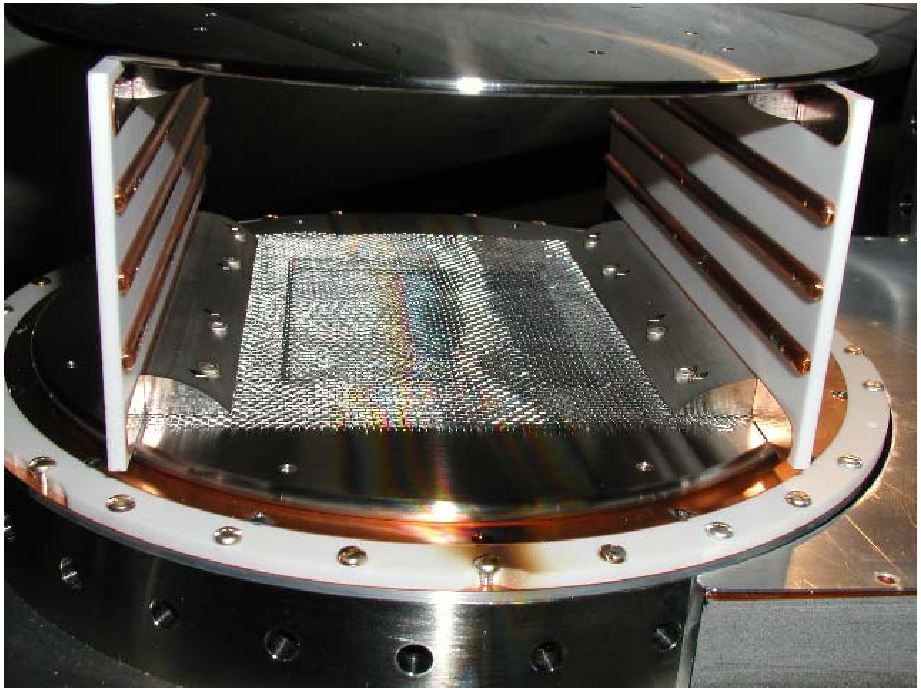


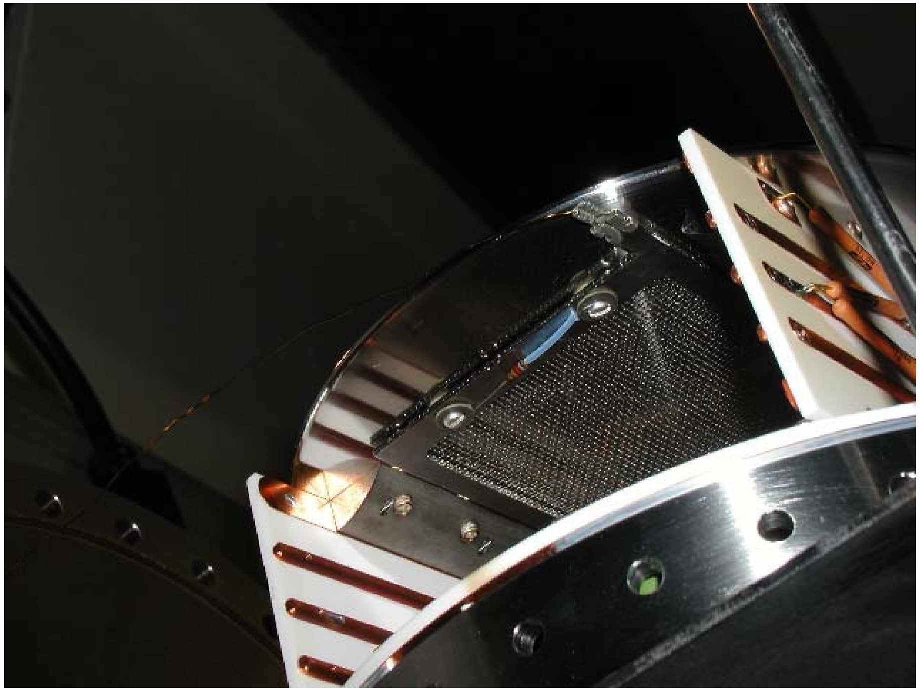
DESY IPM

Fermilab IPM

- Mark-II details

RF Shield Over MCP

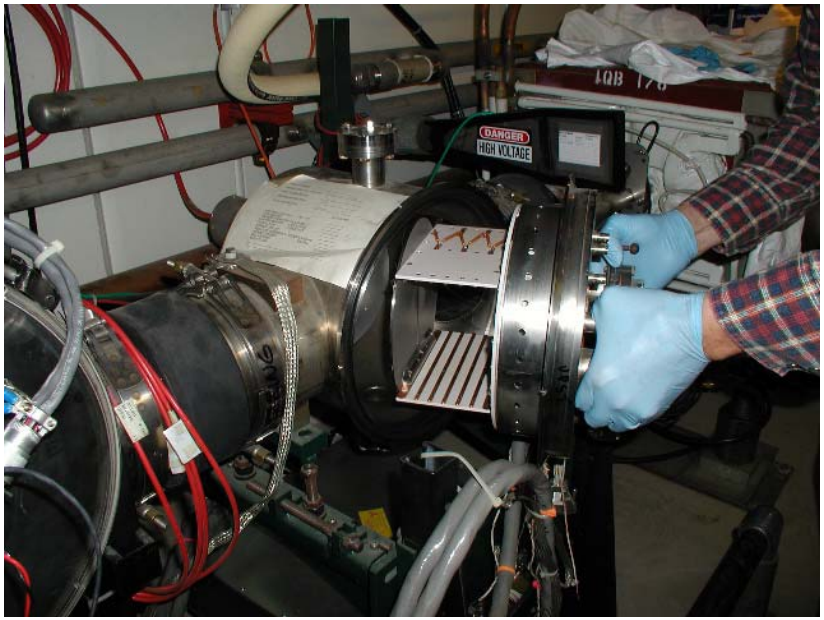




Secondary Screen Grid

J.Zagel

Internal Structure, FNAL IPM.

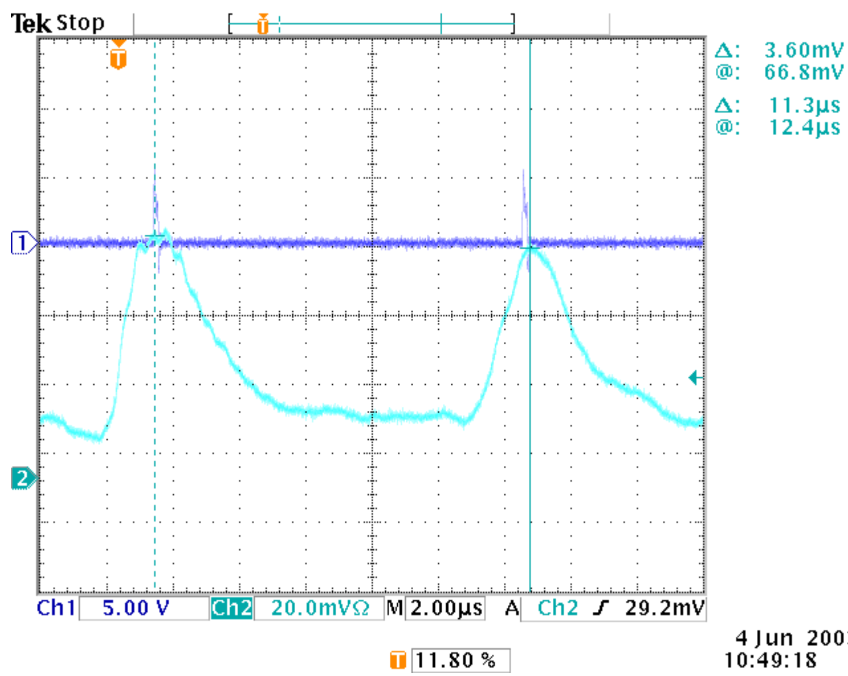


- Main Injector Electrostatic Unit
- J.Zagel

Signal and Timing

- Typical Amplified Strip Signal
- Relative to Beam Sync Clock

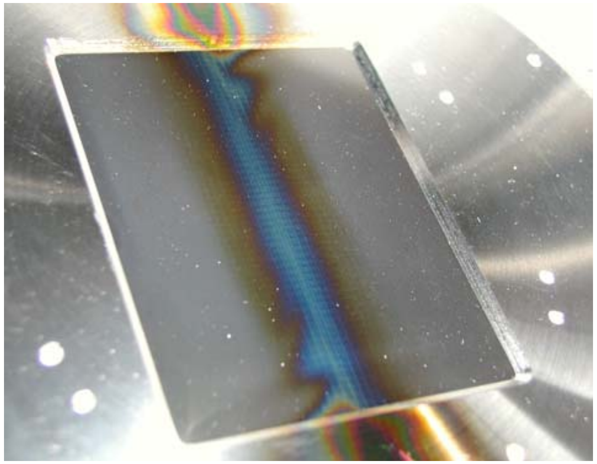
(Captured in Recycler)

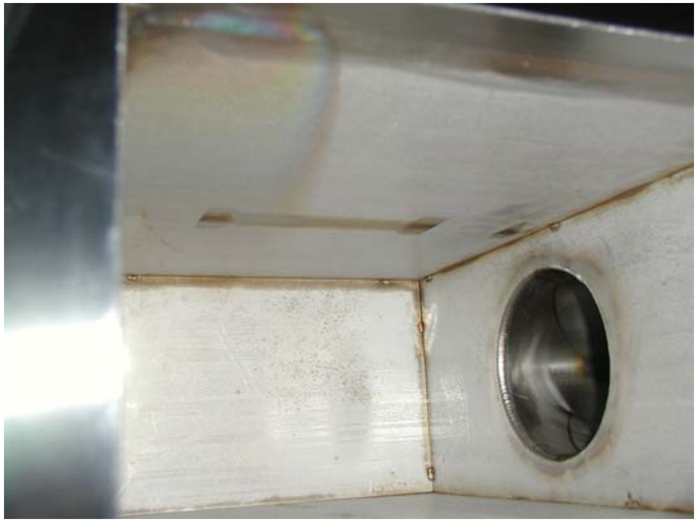


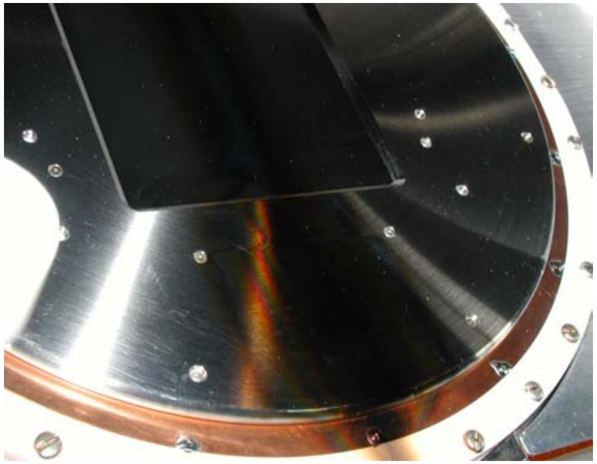
J.Zagel

Interesting Observations

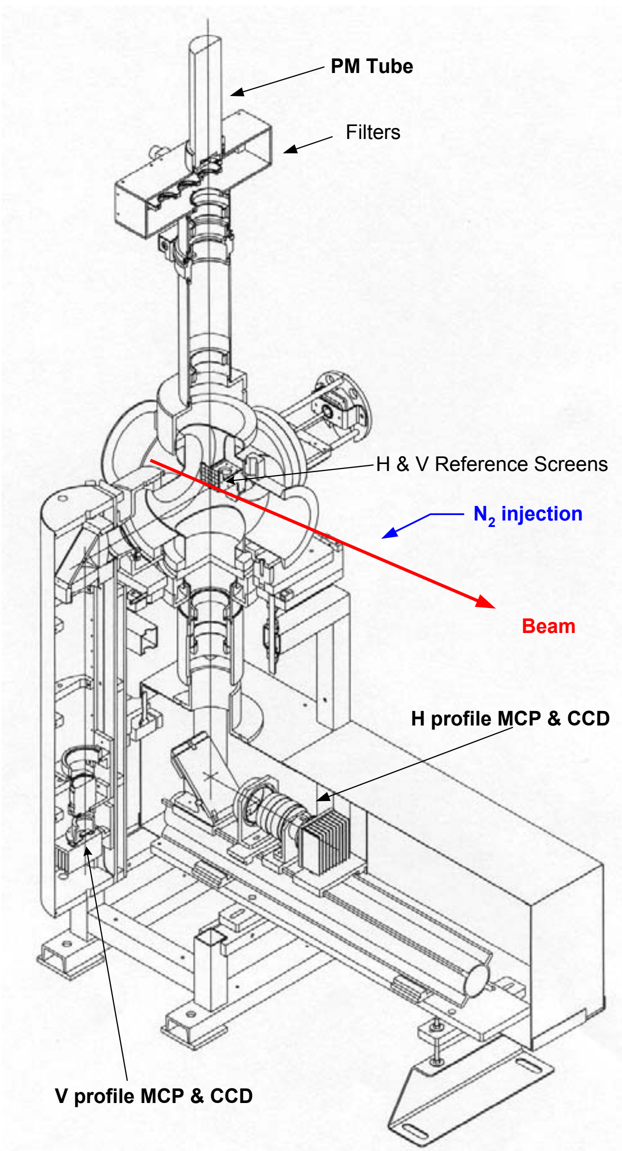
- Plate Discoloration from long term exposure to beam
  - Reason unknown so far







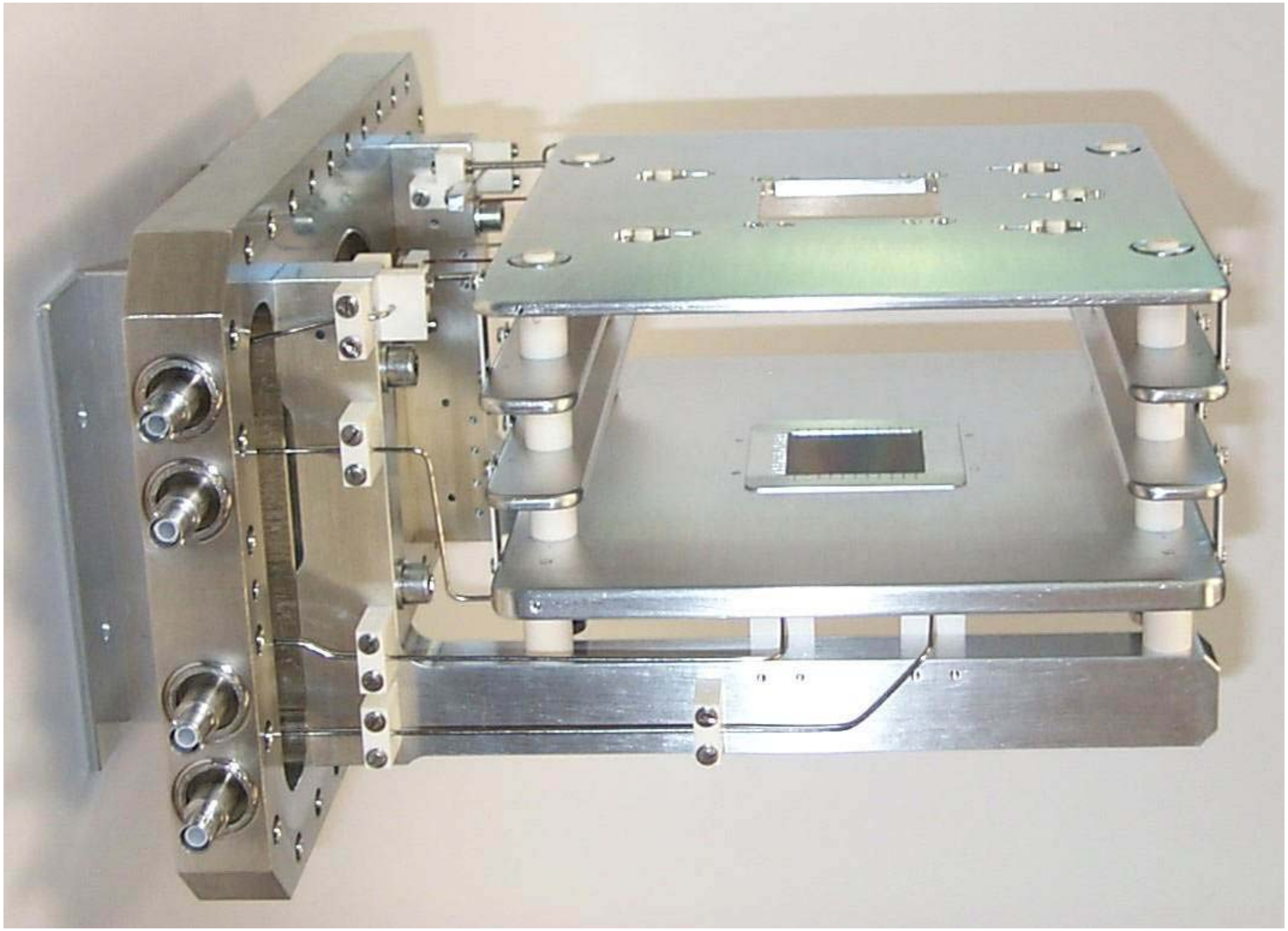
CERN Luminescence Profile Monitor



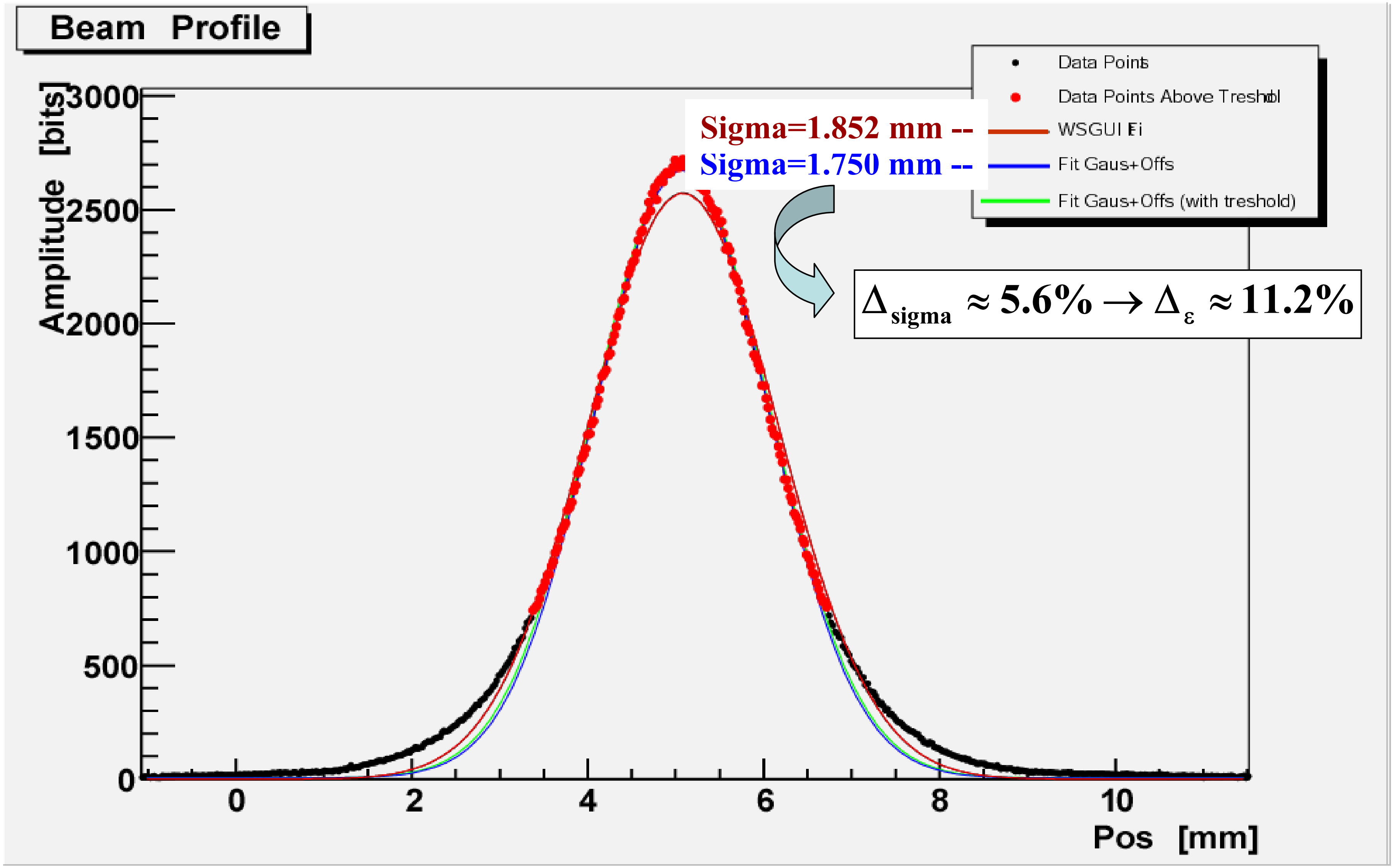
- It works with N_2 injection
- 1 light channel is going to a PM for gas-luminescence studies (decay time etc.)
- 2 channels are used for profile measurements:
  - The H channel is in air: it showed high background with LHC beam, due to beam losses
  - The V channel is in vacuum
- The MCP has a pre-programmed variable gain over cycle

  (it showed some problems to log on timing events)

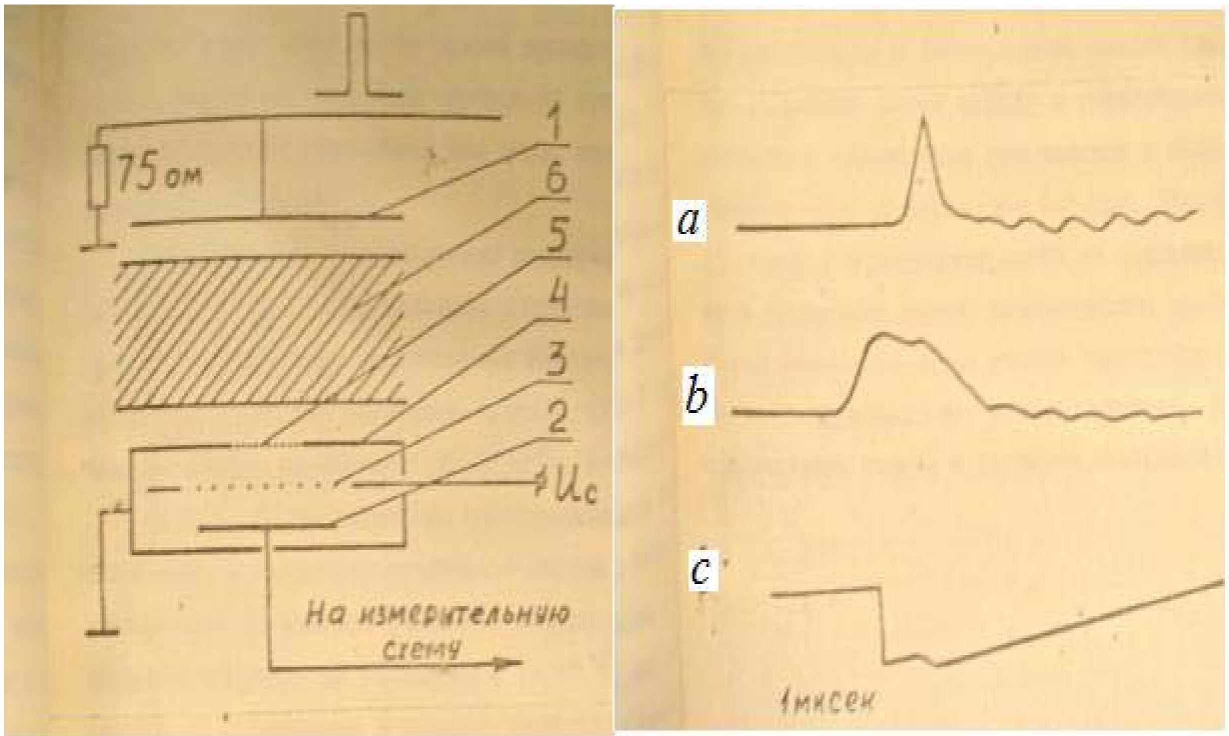
CERN IPM inside



CERN Beam profile. The Fitting Strategies



Secondary Particles detector with repeller, INP,1967



Secondary particles detector:

1-reflection plate; 2-collector; 3-retarding grid; 4-shilding;

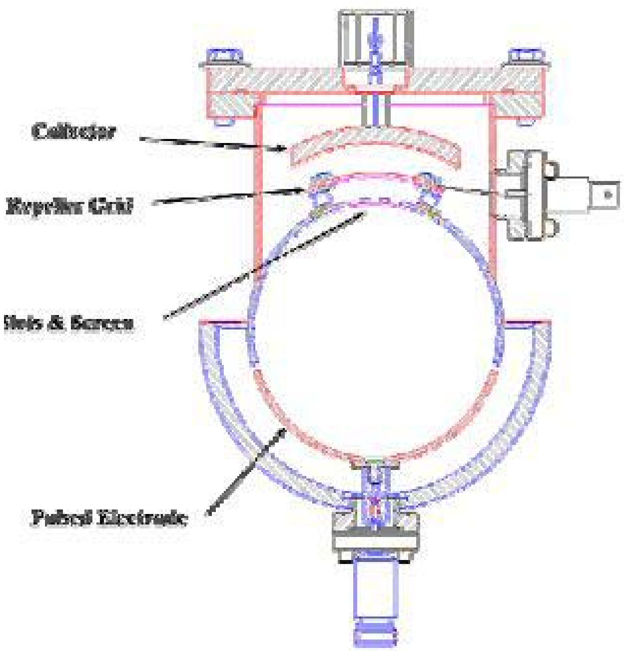
5-grid; 6-beam. a -helium ion;b -nitrogen ion;c -electrons.

ANL Fast collector with repeller

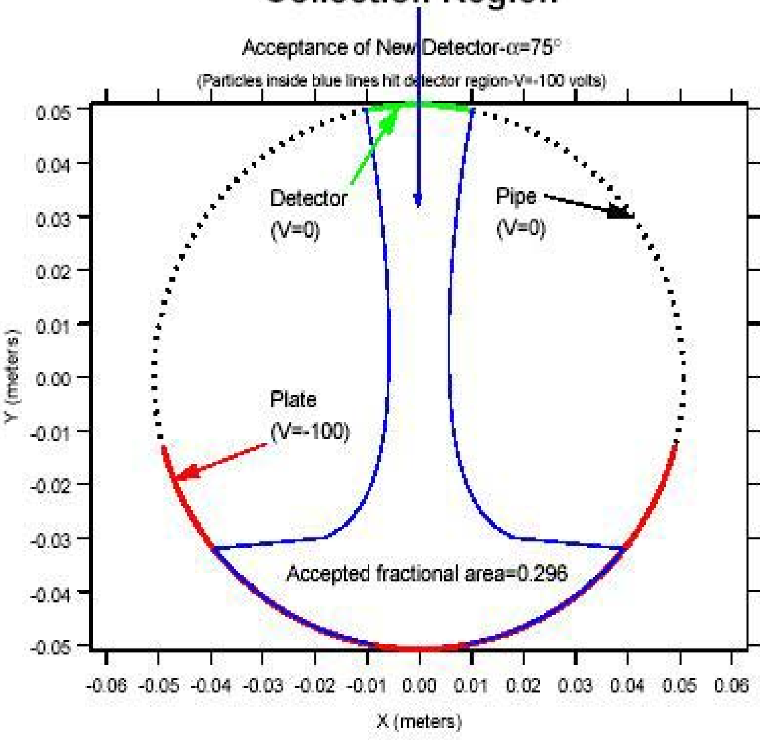
Electron Sweeping diagnostic

- Designed by A. Browman to measure e-cloud surviving passage of the gap
- Short HV (~1kV) pulse is applied to electrode to sweep electrons into RFA

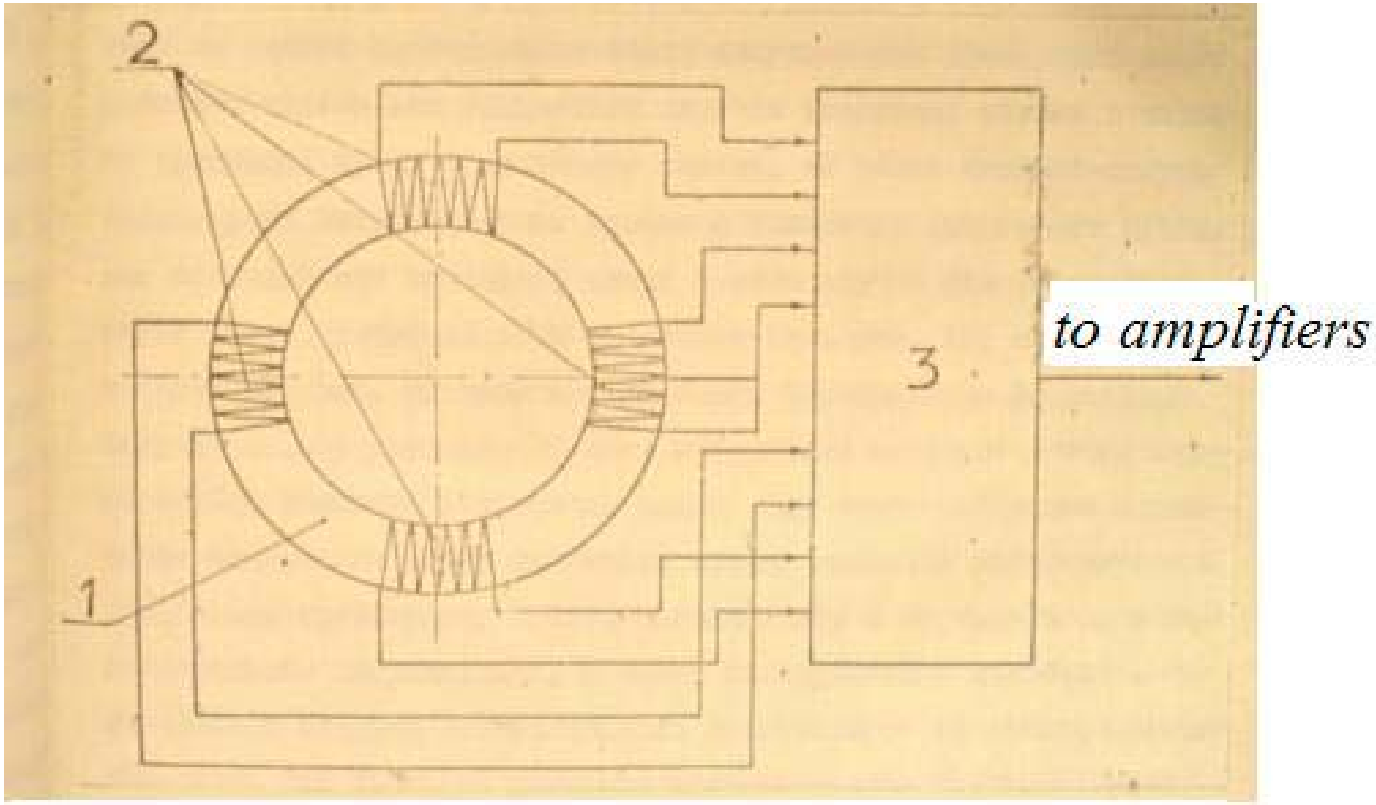
Cross-section



Collection Region

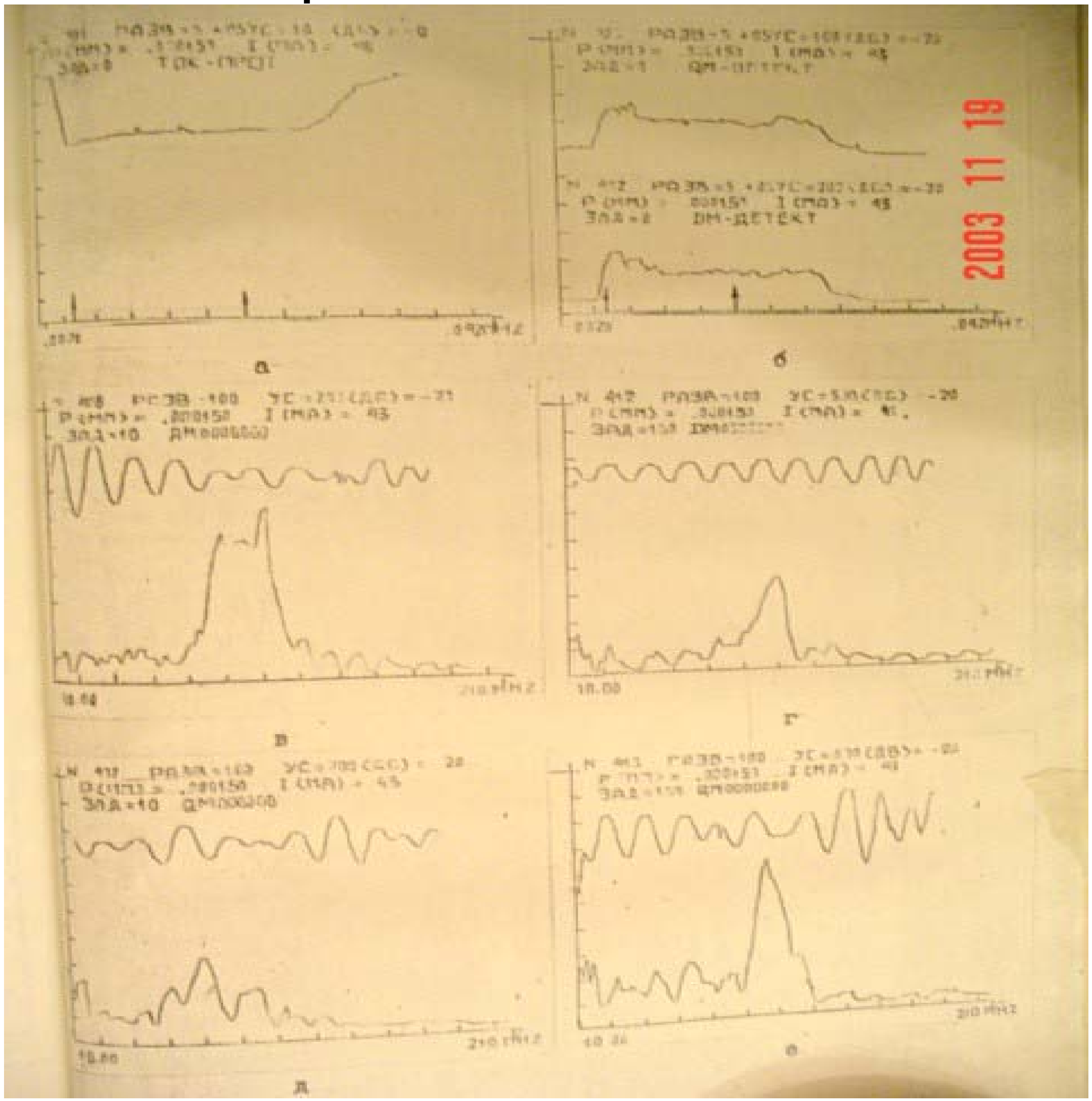


Inductive BPM, INP,1967



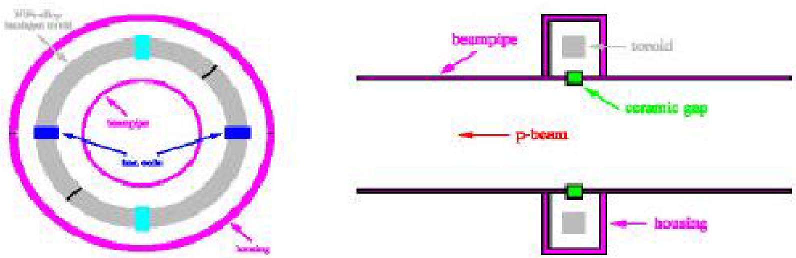
1-ferrite ring; 2-coils; 3-commutator.

Signals and spectrum from inductive BPM



Inductive BPM (DESY).

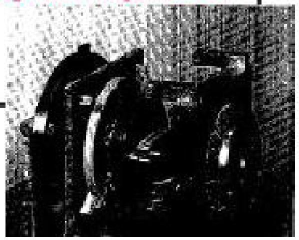
Inductive Beam-Position Pickup



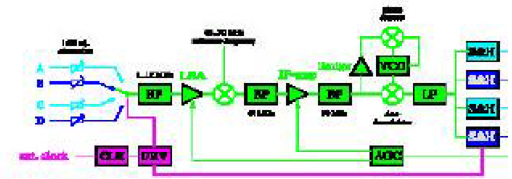
Schematic of the inductive beam-position pickup.

- Circular beampipe of 84 mm diameter aperture.
- 10 mm wide ceramic gap.
- 134 mm diameter NiFe-alloy bandaged toroid transformer with 4 orthogonally arranged single-loops (electrode-coils).
- Normalized sensitivity $\Delta/\Sigma \approx 1.2\%/\text{mm}$ with a high linearity over the full aperture.
- Typical signal levels range between some 10 mV at flat-bottom and several volts at flat-top energy (peak-peak amplitudes, 50 Ω termination).
- 30 kHz...250 MHz (-3 dB) bandwidth.

DESY III BPMs



Electronics Hardware

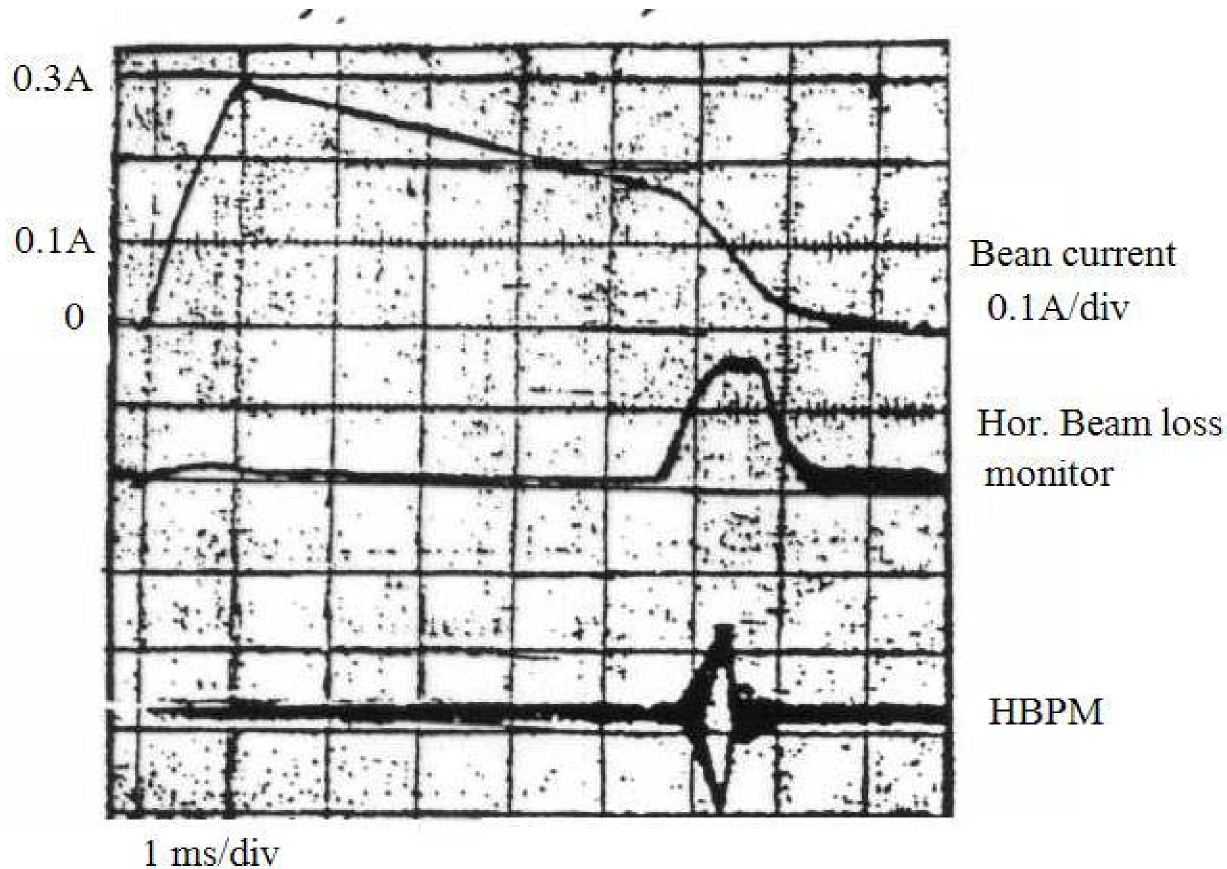


Schematic of the modified analogue *BL* BPM-electronics.

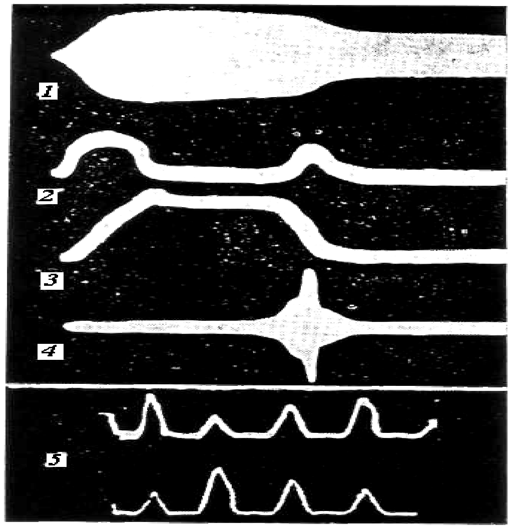
Wherever possible, commercial subsystems and r used for electronics hardware of the BOM/BPM-sy

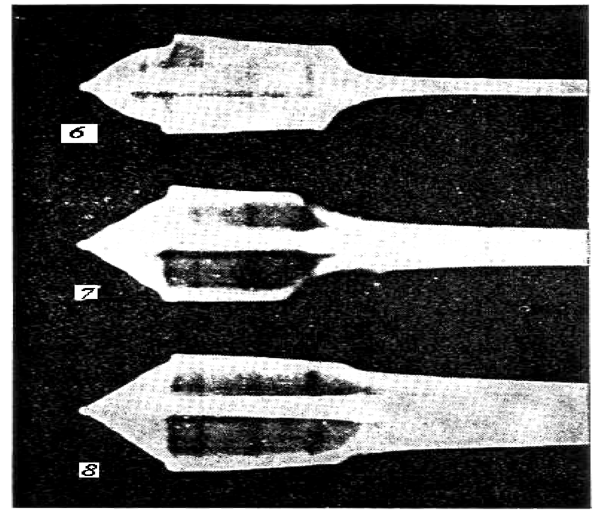
- A modified *BERGOZ* BPM-electronics for the nal processing:
  - Input frequency range ≈ 3...10 MHz, to guar tection of any number of bunches in the ring.
  - IF center frequency of 60 MHz, 500 kHz band
  - External LO input, driven from the rf-synchr III low-level rf-synthesizer (≈ 63...70 MHz).
  - Changes on the internal clock frequency and /
- Two C-size VXI digitizer-boards (*VXI-VM2616*) with 64 independent 16-bit AD 512kWord of total memory.
- A PC plug-in delay generator (*Stanford DG13* livers the ADC trigger.
- Usual PC-hardware, including a IEEE1394 "Fir the VXI-crate.

Transverse instability in the INP PSR, bunched beam (1965)



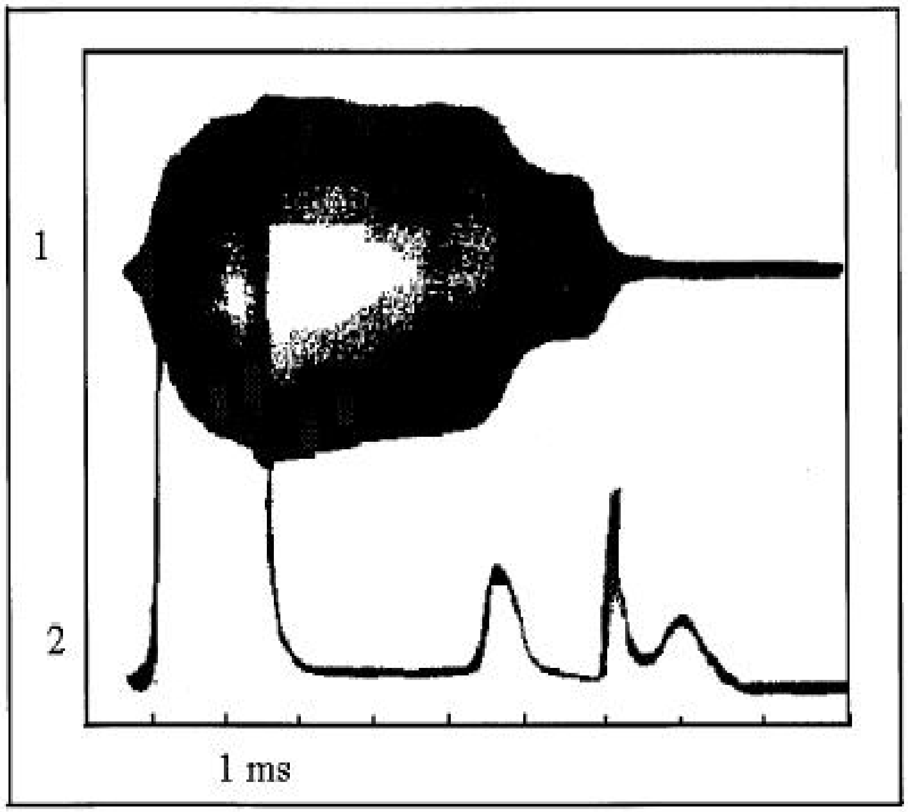
Transverse instability of bunched beam in INP PSR (1965)





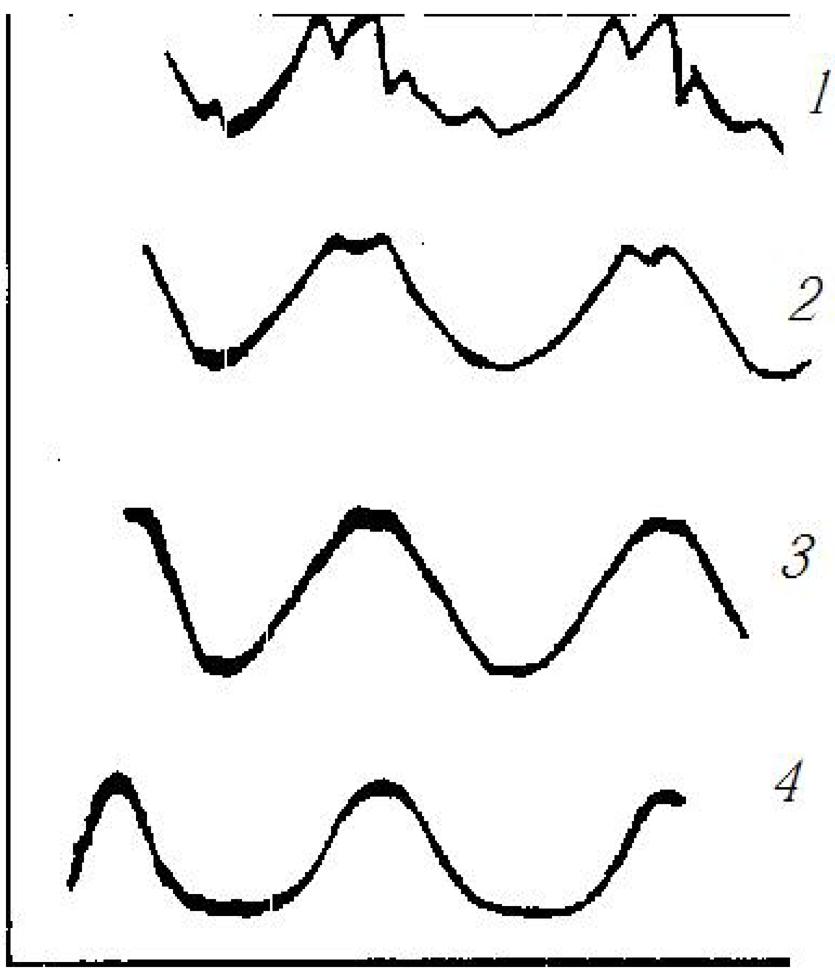
Transverse e-p instability in INP Proton storage ring (PSR),
1965. *bunched beam*   *Injection time is 1ms*
1-pick up electrode signal; 2-beam loss monitor;
3-beam intensity; 4-Rad.BPM; 5-radial pick ups;
6-pick up signal Urf=1.4kV; 7-pick up signal Urf=2.8;
8-pick up signal Urf=4.2kV;
9- beam intensity below threshold for instab;
10-beam intensity above threshold for instability, no fied back stabilization; 11- beam intensity above threshold for transverse instability, fied back stabilization ON.

Transverse instability of bunched beam with a high RF voltage



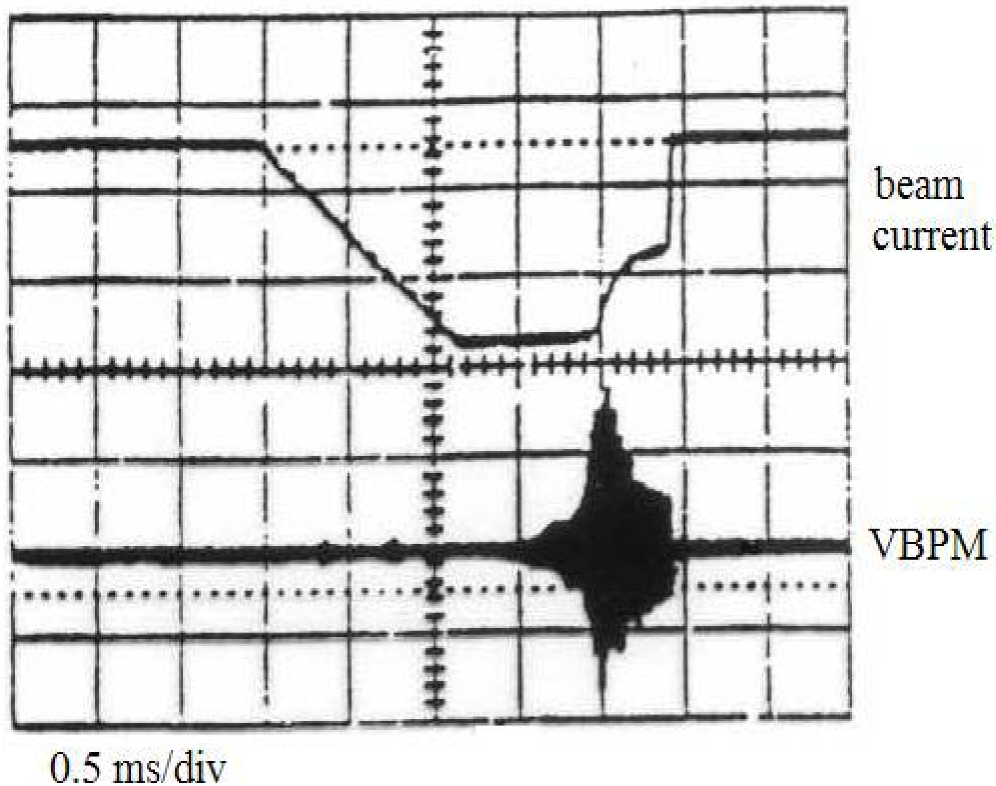
1-ring pickup, peak bunch intensity ;
2-radial loss monitor.
Beam was deflected after Instability loss.
Two peaks structure of beam after instability loss.
Only central part of the beam was lost

Evolution of bunches profiles in INP PSR



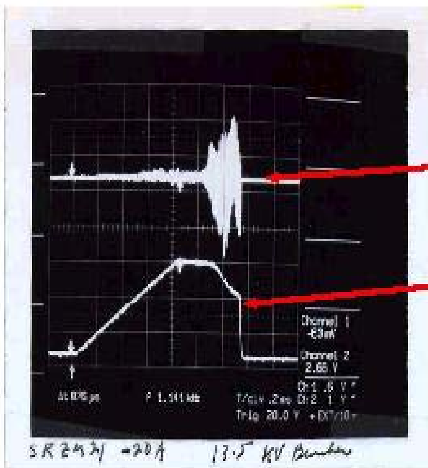
1- 0.05 ms(100 turns);
2- 0.4 ms(1000 turns);
3- 0.8 ms (3000 turns);
4- 2.8 ms, before start
Transverse instability.
Bunches period 188 ns
Coasting beam injection

Transverse instability in Los Alamos PSR, bunched beam (1986)



e-p instability in LA PSR, bunched beam

Well Established ep Instability Characteristics at PSR

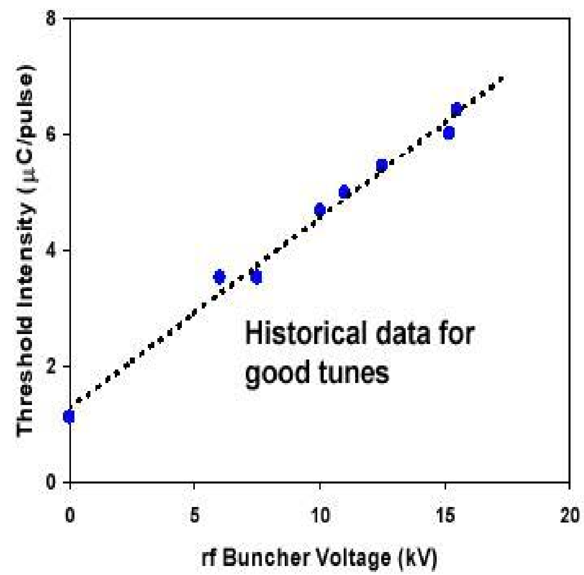


Instability Signals

BPM ΔV signal

CM42 (4.2 μC) (Circulating Beam Current)

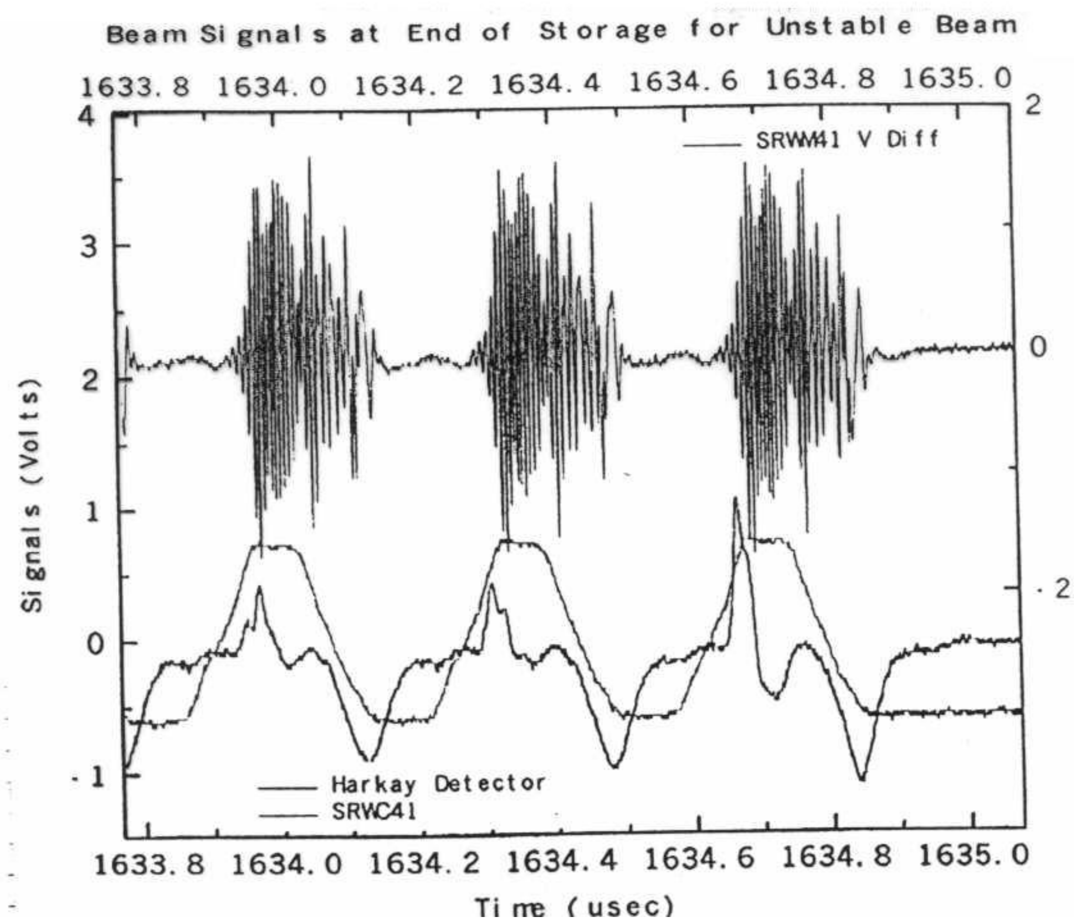
Control by rf buncher voltage



- Growth time ~ 75 μs or ~200 turns
- High frequency ~ 70 – 200 MHz
- Controlled primarily by rf buncher voltage
- Requires electron neutralization of ~ 1% (from centroid model)

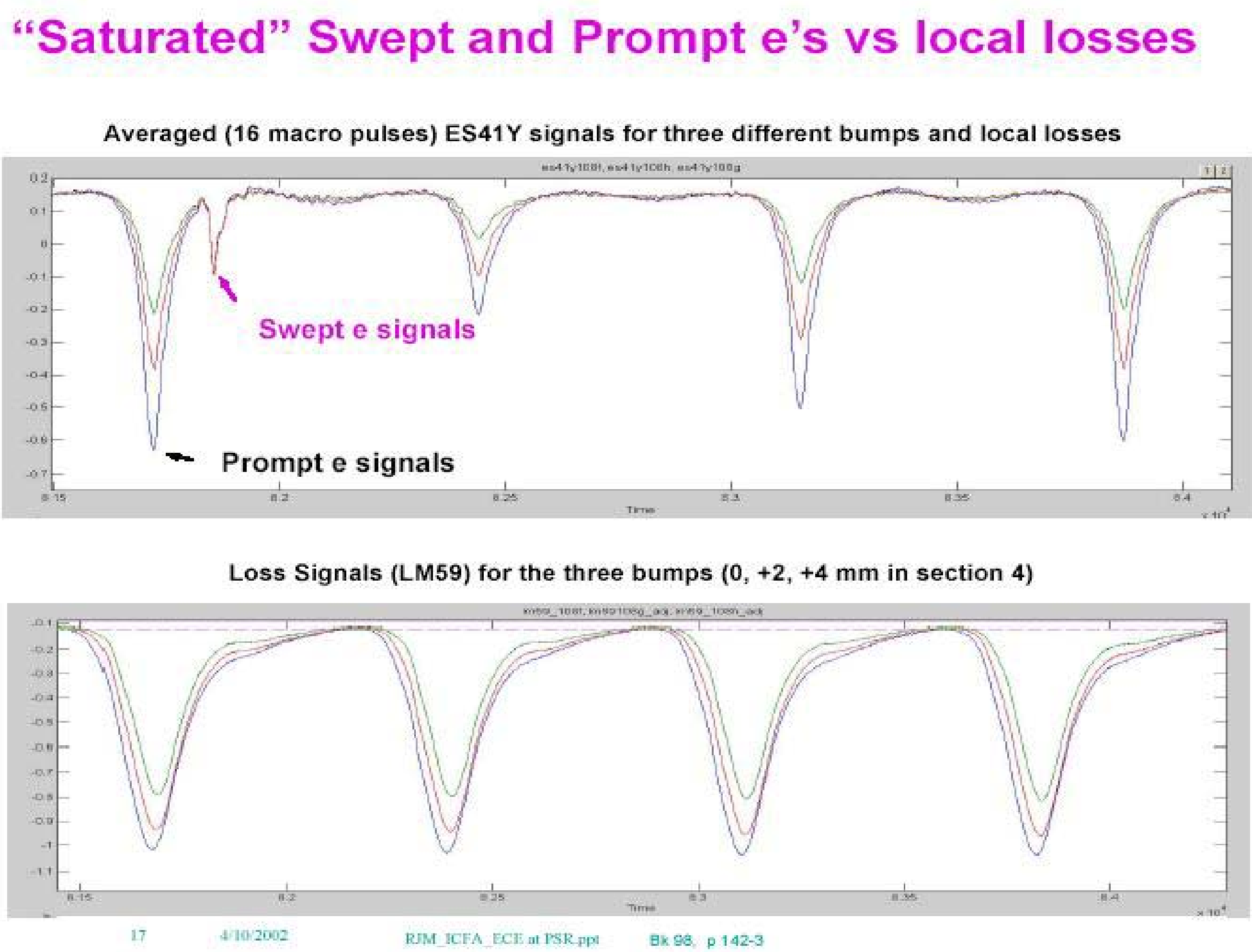
Macek, LANL

Pickup signals and electron current in LA PSR



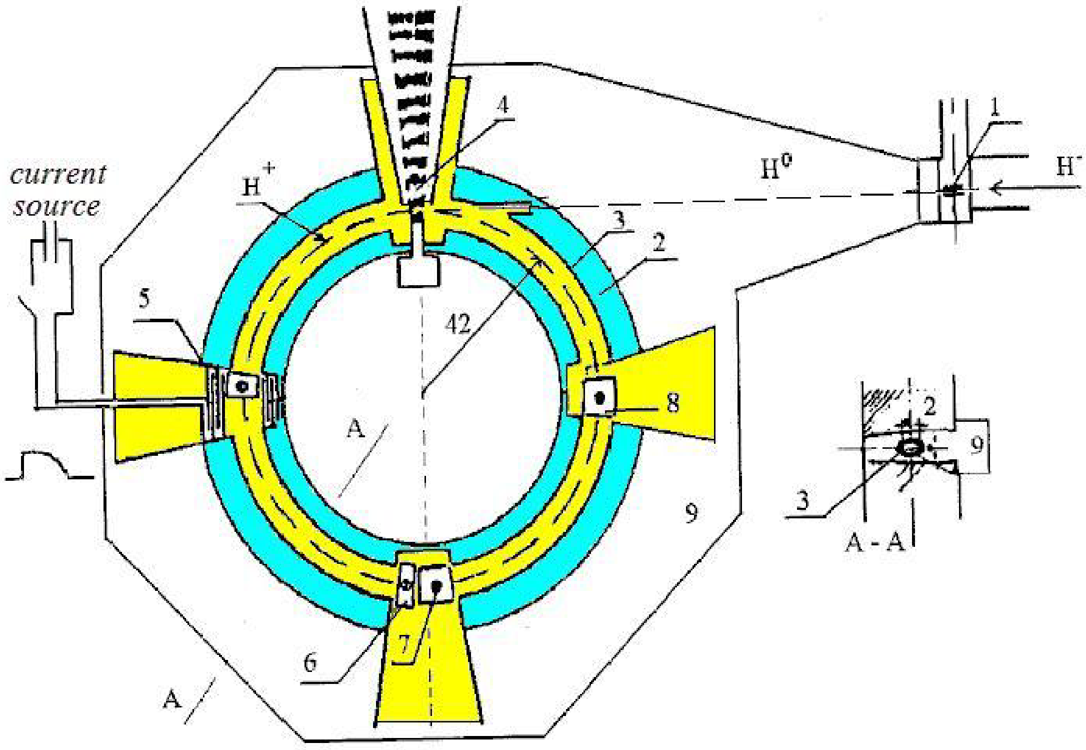
R.Macek, LANL

Electron signal and proton loss in LA PSR



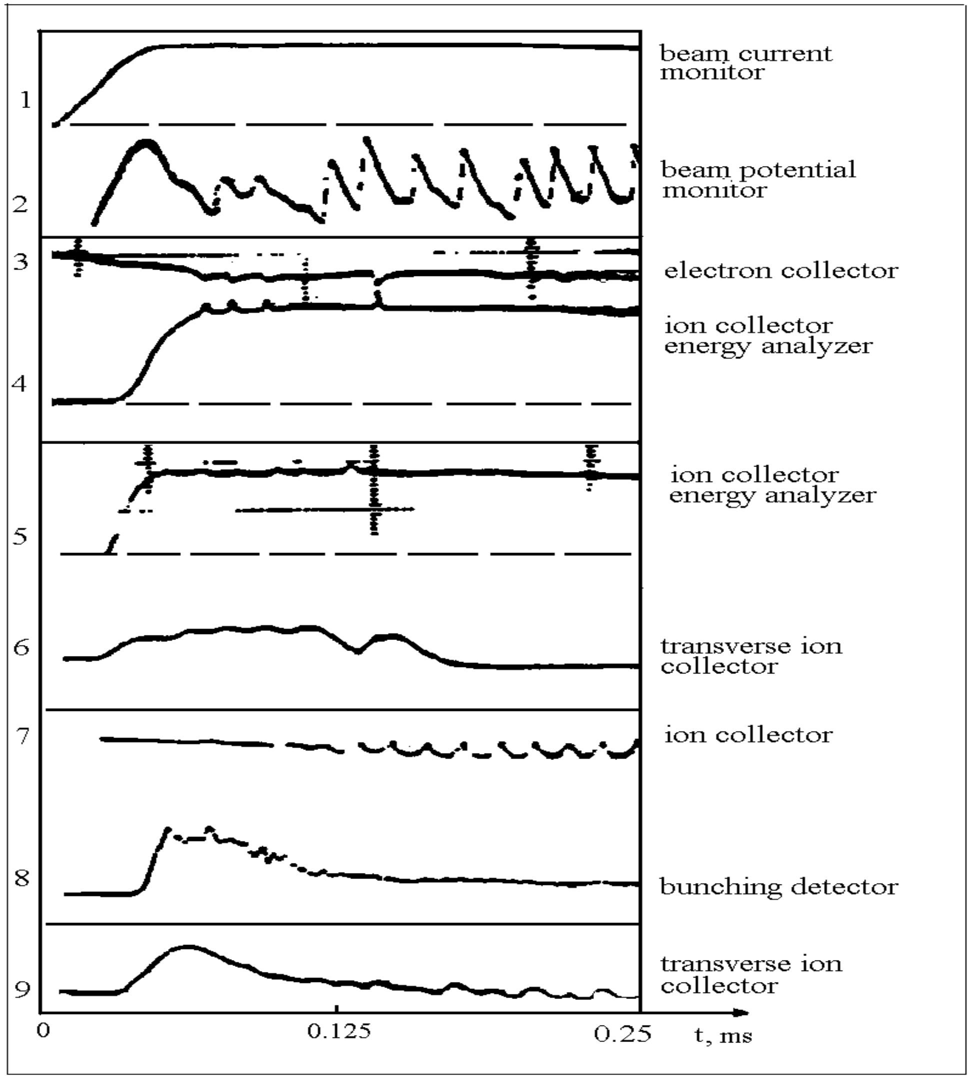
R.Macek, LANL

PSR for beam accumulation with inductive acceleration



1-first stripper;
2-magnet pole n=0.6;
3-hollow copper torus with inductance current;
4-main stripper;
5-accelerating gap;
6-ring pickup; 7-BPMs;
8-Res.gas IPM;
9-vacuum chamber.
FC; quartz screens;
Retarding electron and ion collectors/ spectrometers .

e-p instability with a low threshold in INP PSR



1-beam current, N>7e9p

2-beam potential, slow Accumulation of electrons 10mcs, and fast loss 1mcs.

3-retarding electron collector;

4,5-ion collector, ionizing Current Monitor;

6,7-ion Collectors Beam potential monitor;

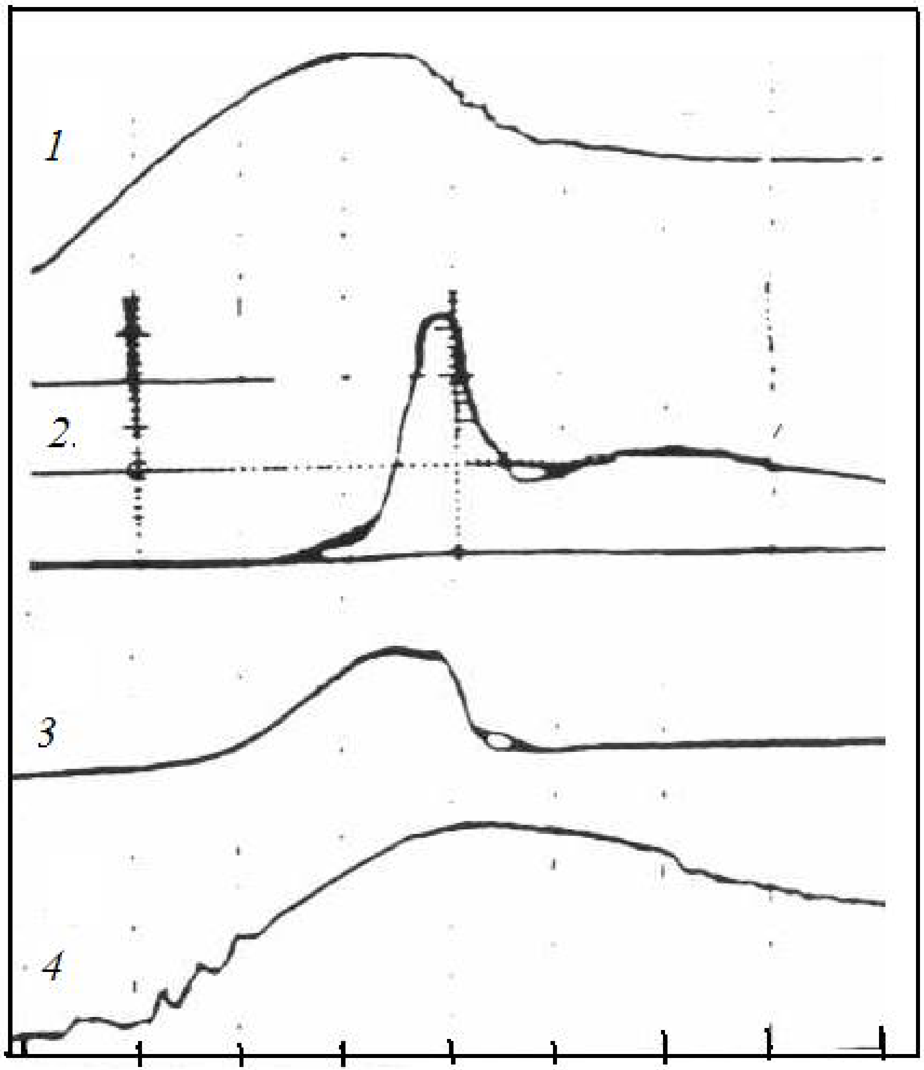
8,9- negative mass Instability.

Injection:

Coasting beam, 1MeV, 0.1mA

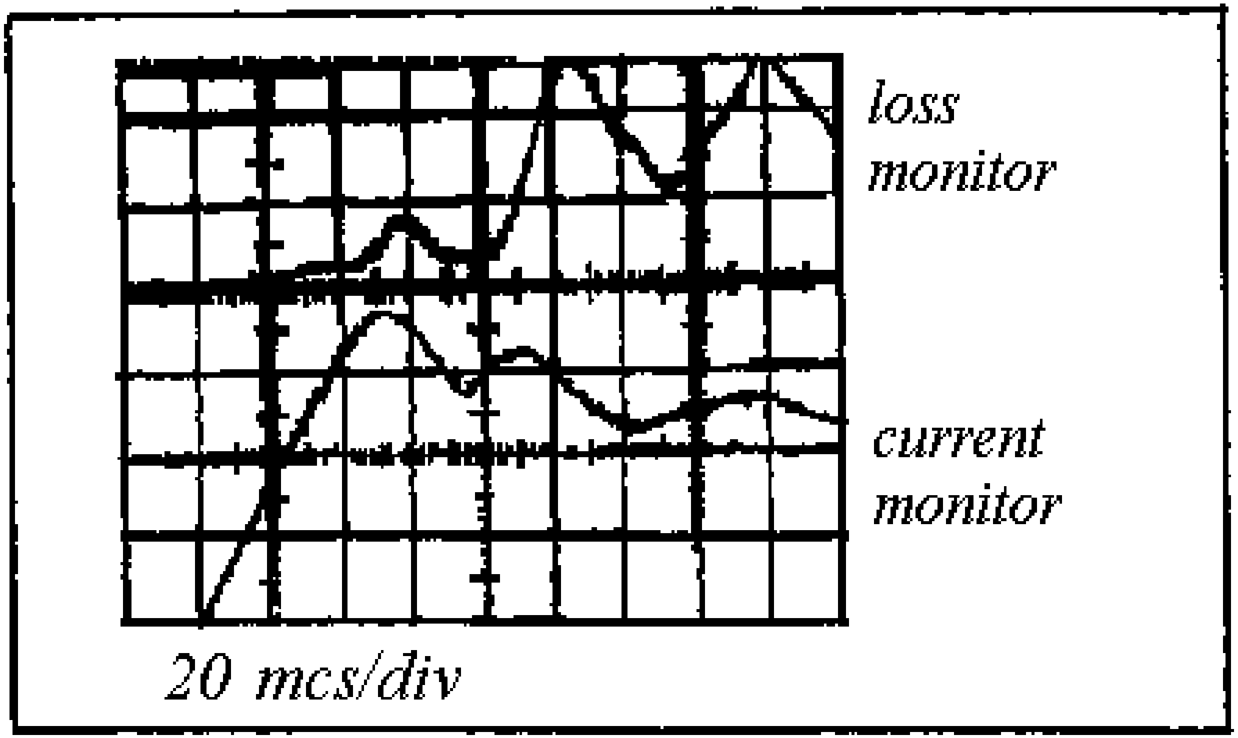
R=42 cm.

Instability of coasting beam in AG PSR, 1967

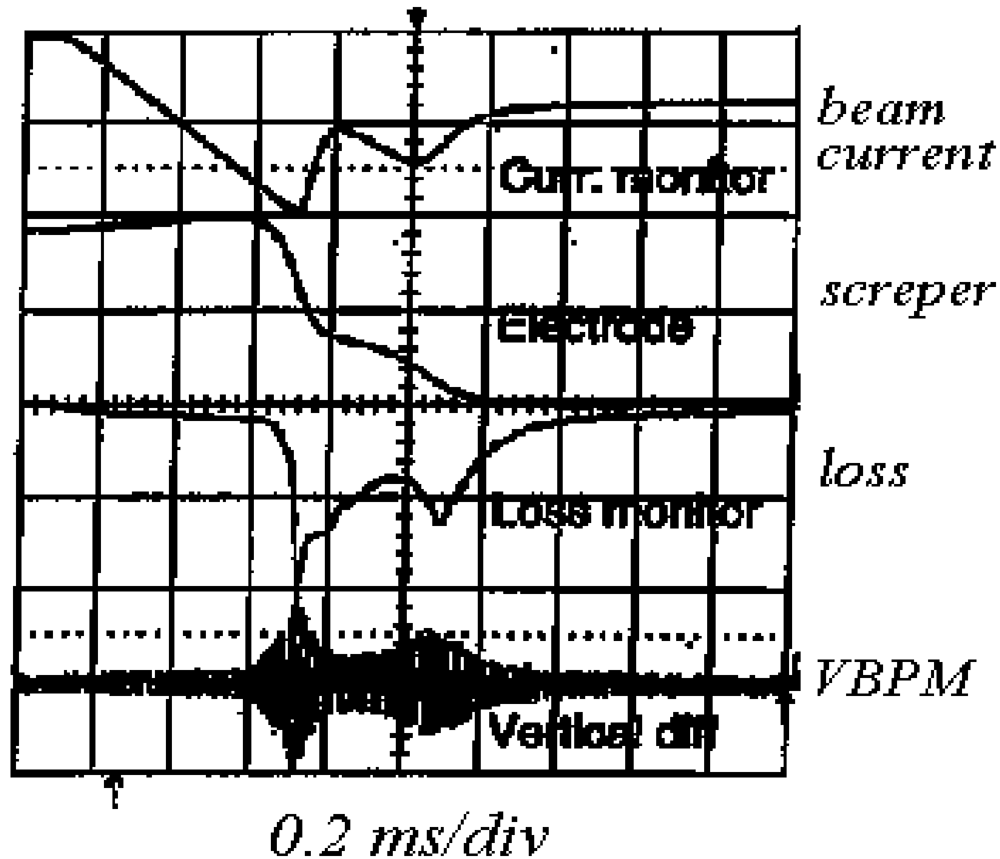


1- beam current
 monitor;
2-vertical proton
loss monitor;
3- radial proton loss;
4-detected signal of
vertical BPM.
20 mcs/div.

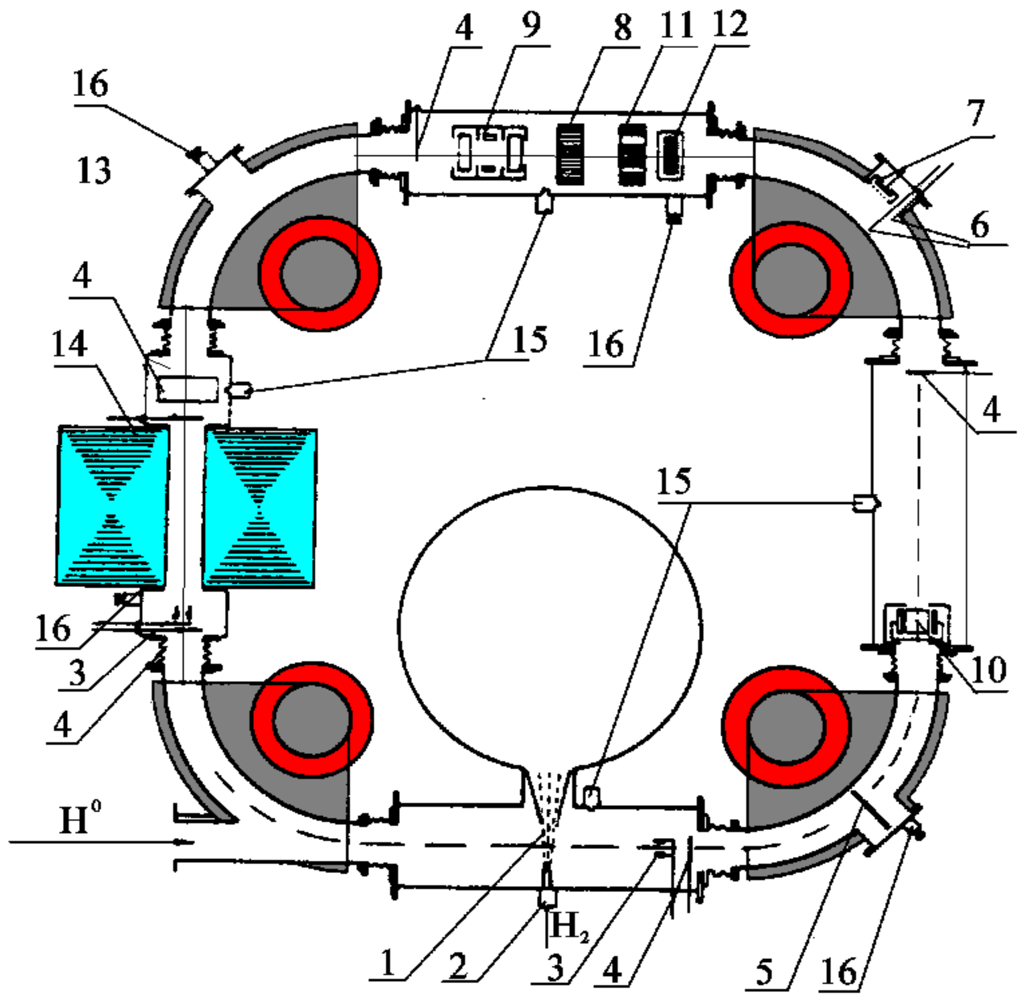
e-p instability of coasting beam in the INP PSR (1967)



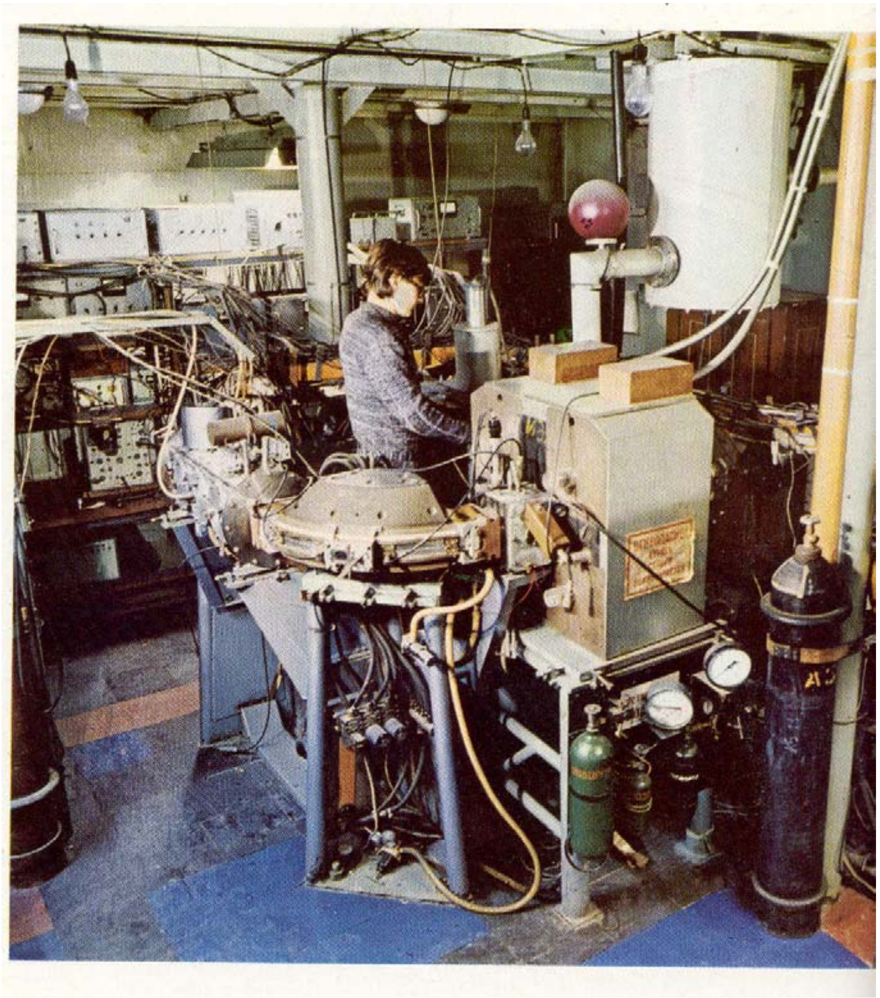
e-p instability of coasting beam in LA PSR,1986



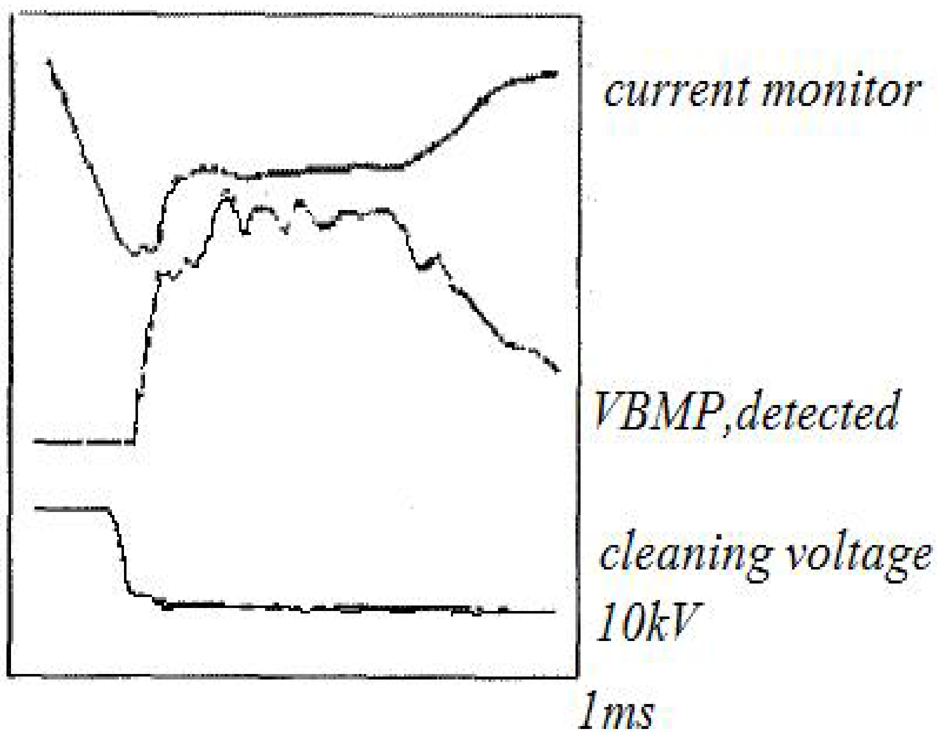
INP PSR for beam above space charge limit



Small Scale Proton Storage Ring for Accumulation of Proton Beam with Intensity Greater than Space Charge Limit

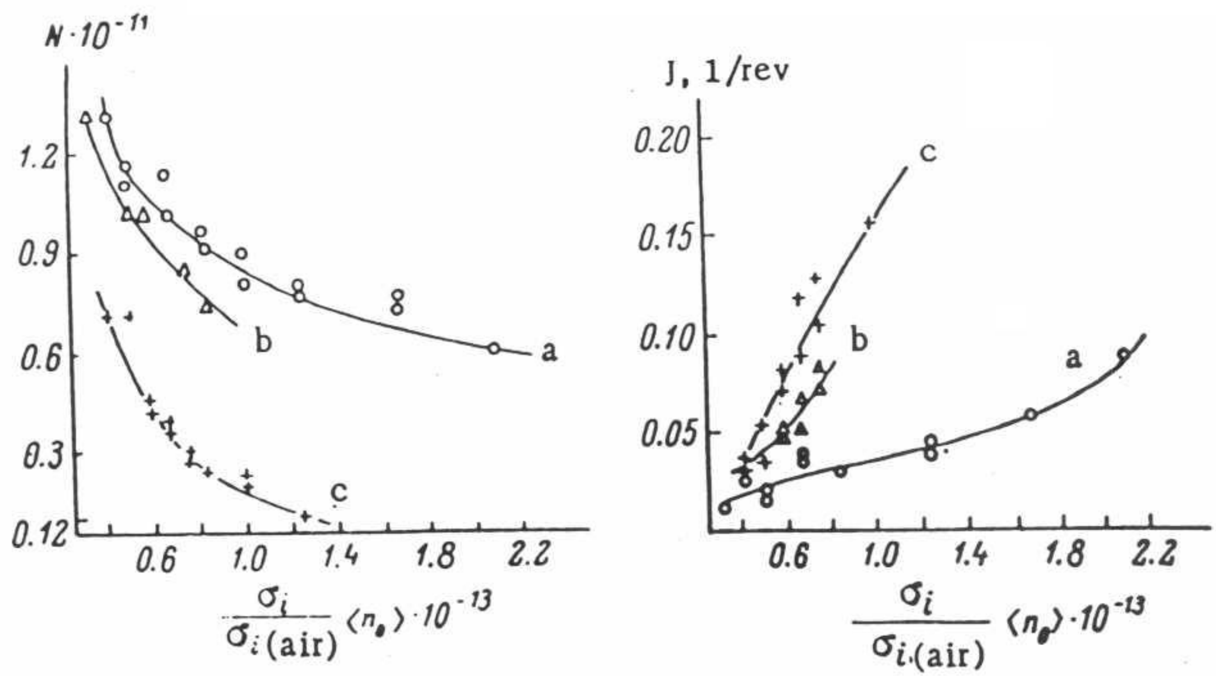


Beam accumulation with clearing voltage



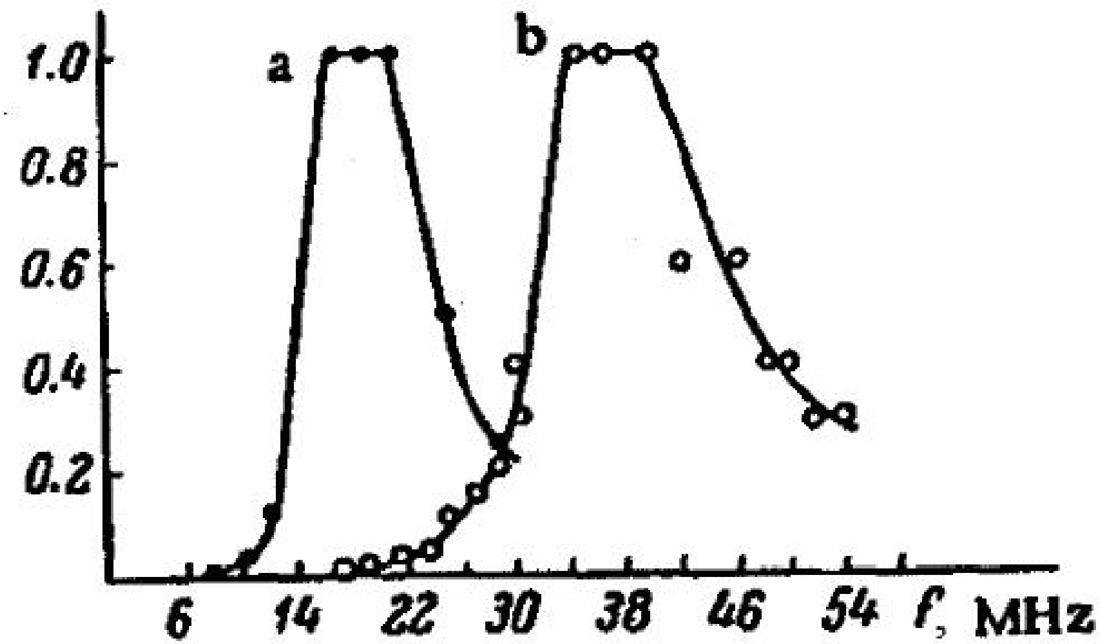
Secondary plasma accumulation suppressed by strong transverse electric field. Vertical instability with zero mode oscillation was observed (Herward instability).

Threshold intensity N (left) and growth rate J (right) of instability as function of gas density n



a-hydrogen; b-helium; c-air.

Spectrums of coasting beam instability in BINP PSR (magnetic BPM)

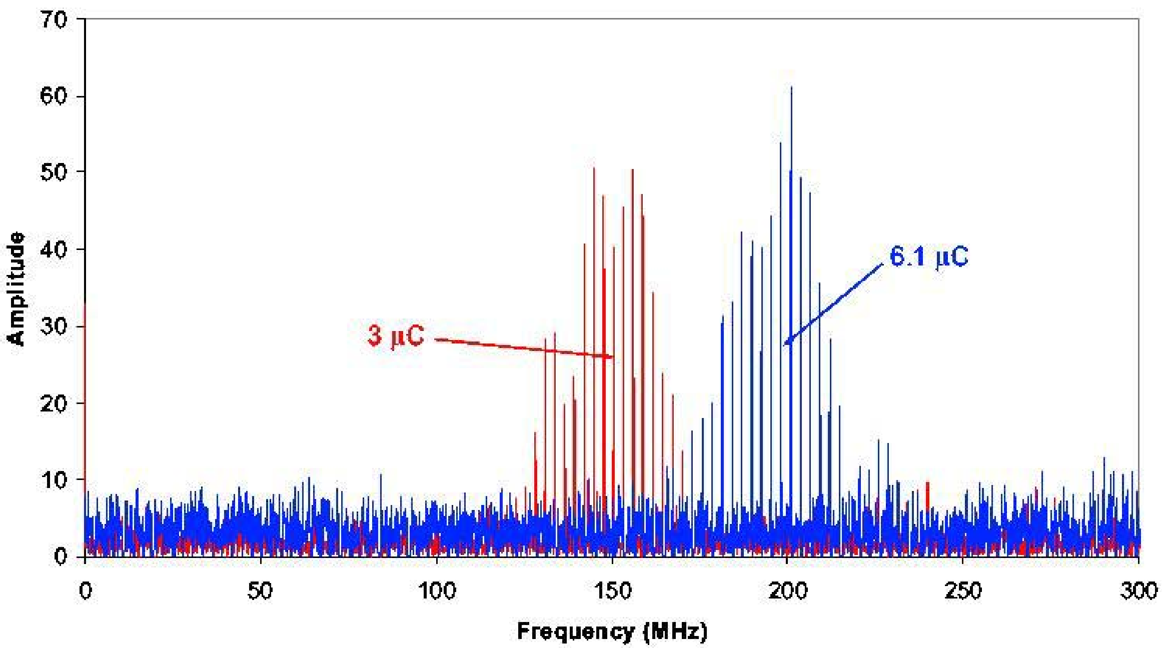


Spectrum of signals from vertical beam position monitor.
a) N=1.7 10^{10} p; b) N= 1.5 10^{11} p.

Spectrums transverse beam instability in LA PSR

Frequency spectra of unstable motion agrees with model

$$\omega_e = Q_e\Omega_0 = 2\pi f = \sqrt{\frac{2Nr_e c^2(1-f_e)}{\pi b(a+b)R}}, \qquad f \approx 230\ \mathrm{MHz}\ (6.1\mu C)$$



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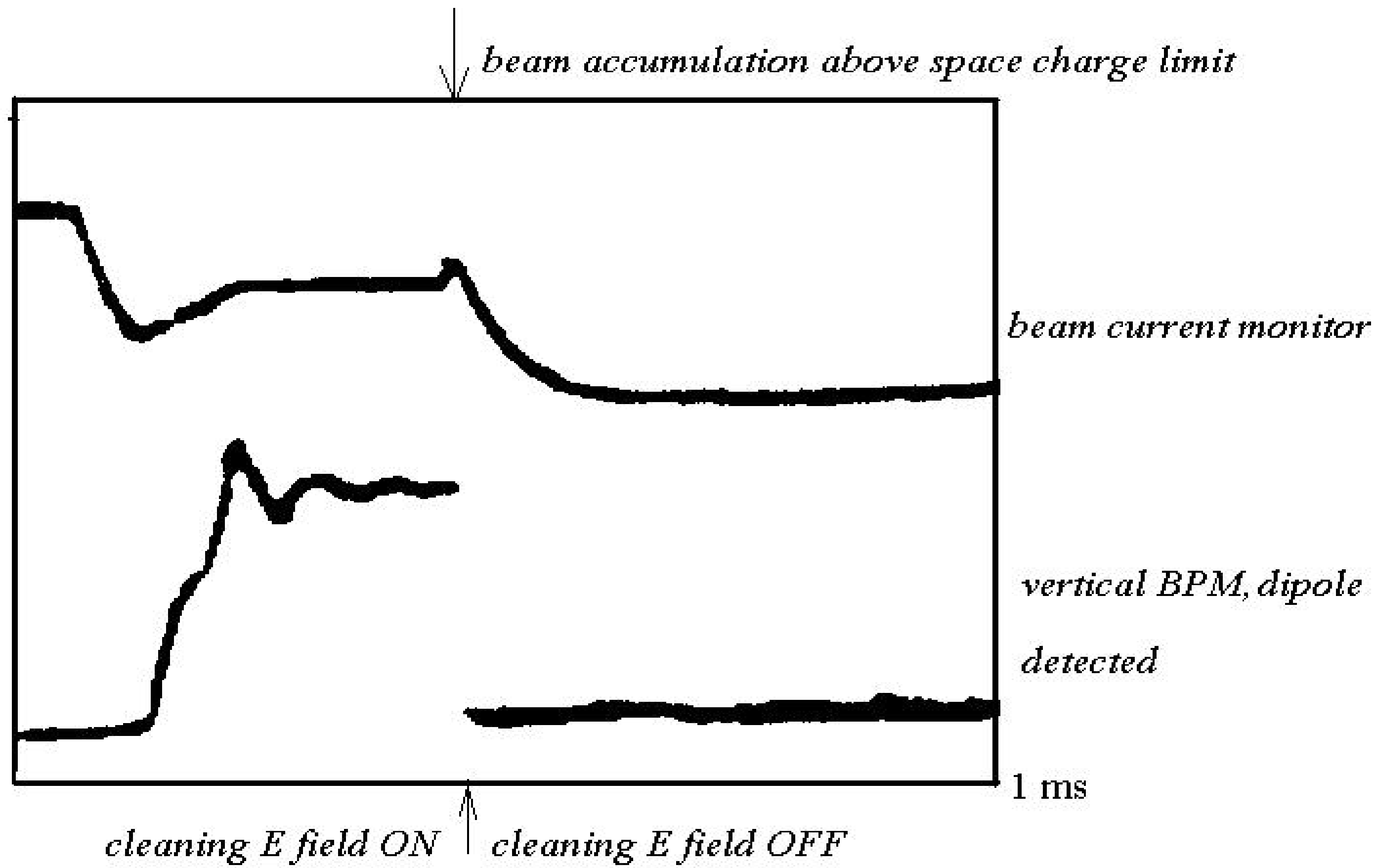
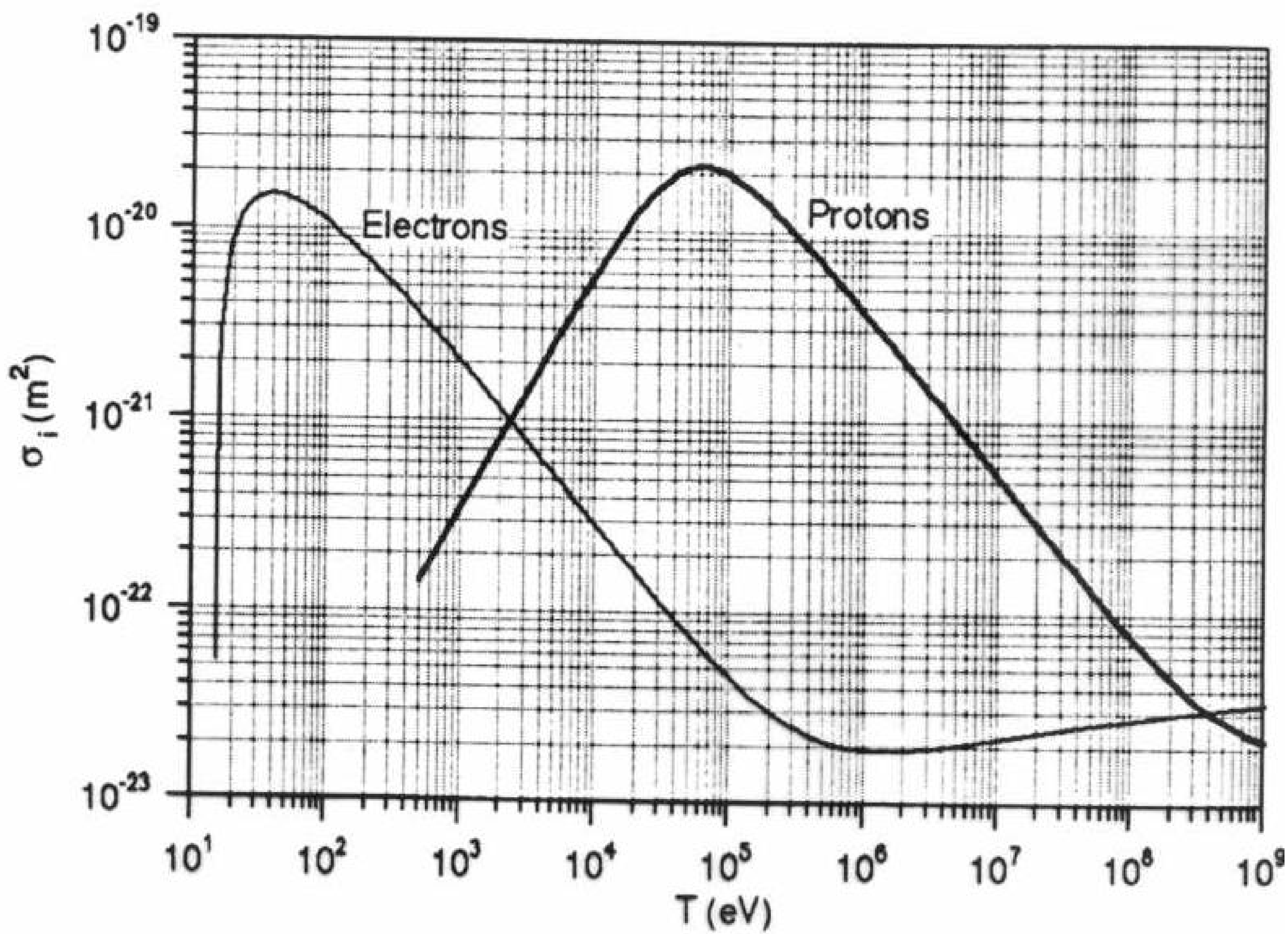
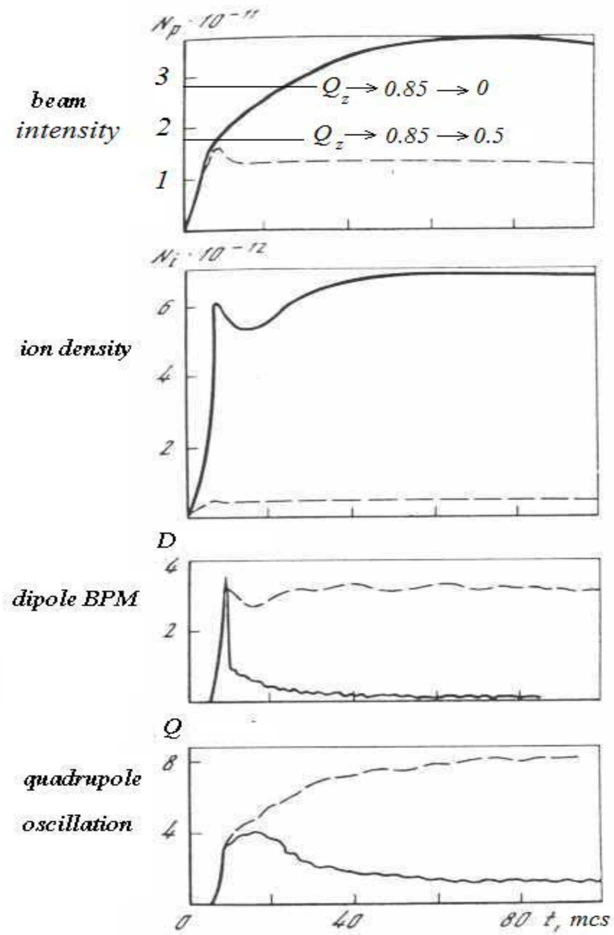
Beam accumulation with space charge neutralization

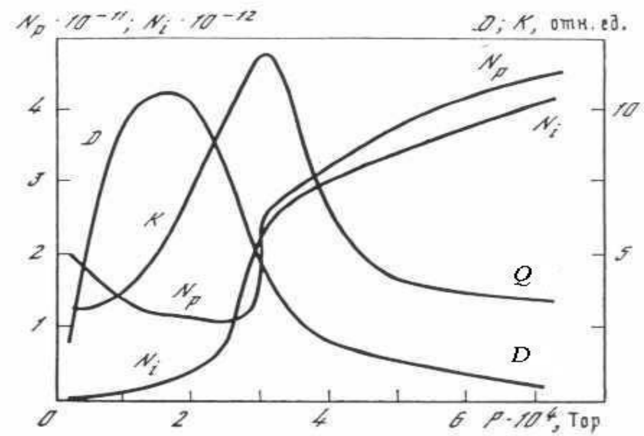


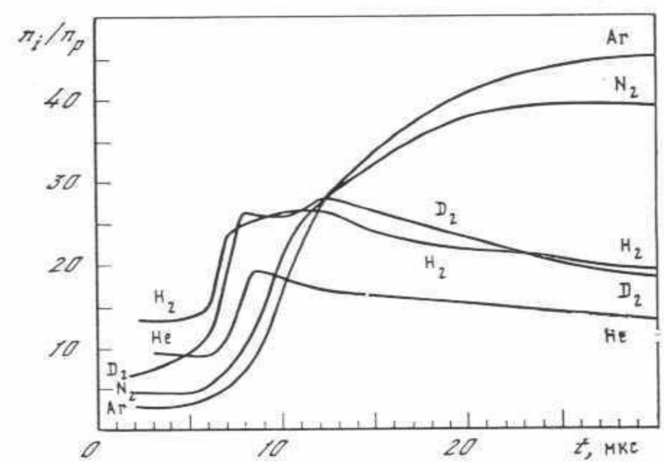
Ionization cross sections for H



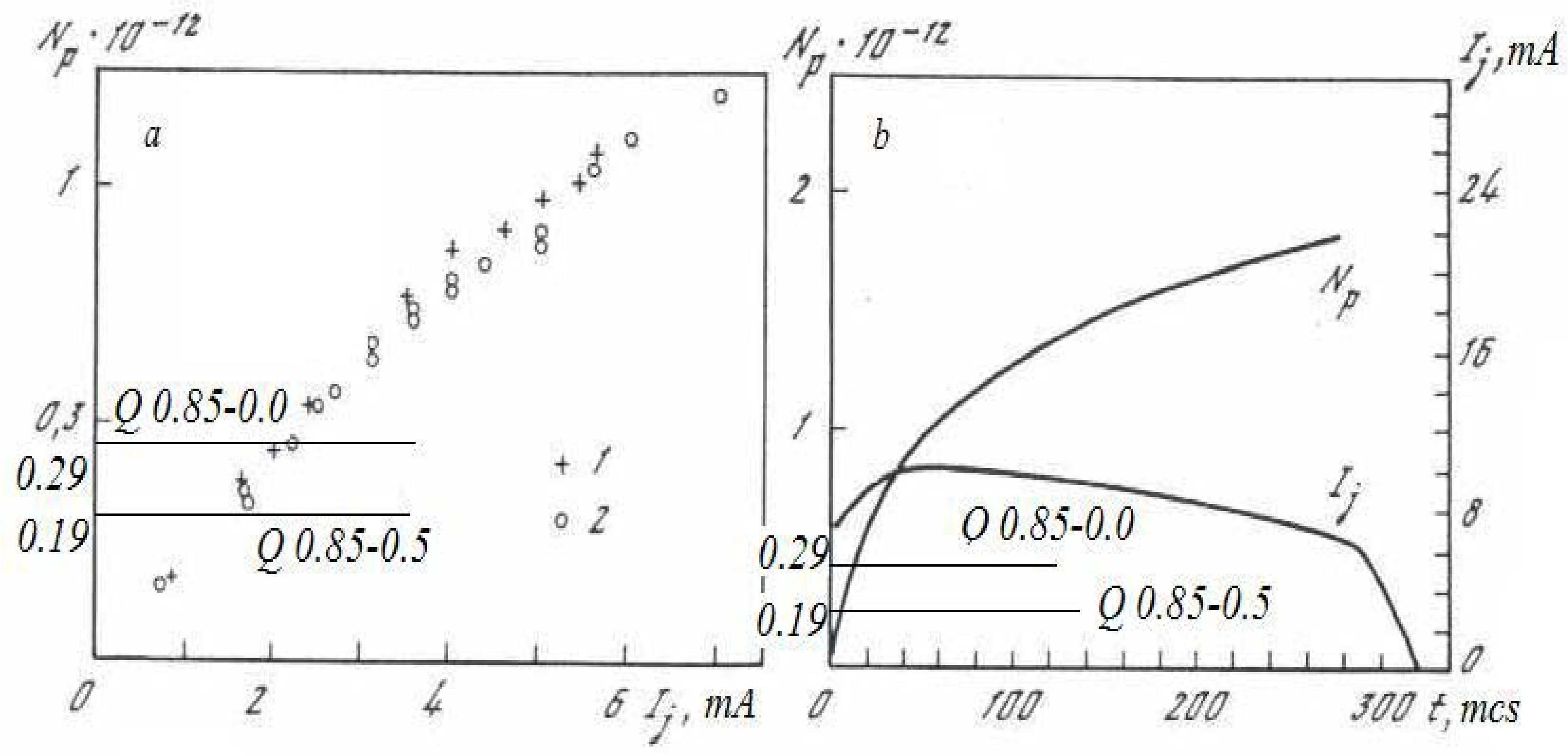
Proton beam accumulation with intensity above space charge limit





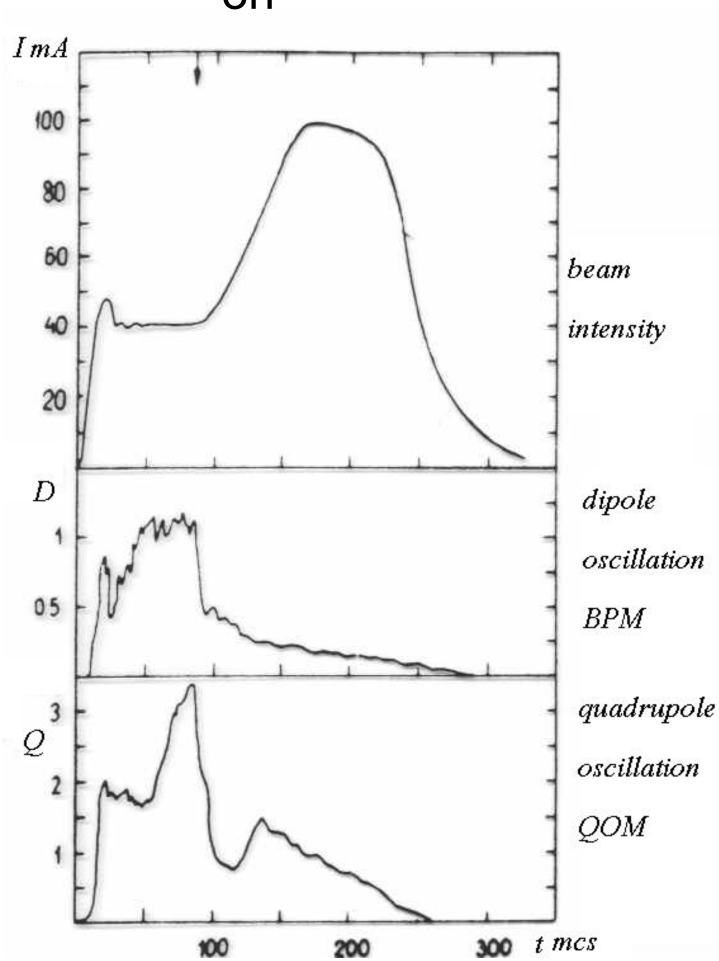


Proton beam accumulation with intensity grater than space charge limit. Dependence of injection current.

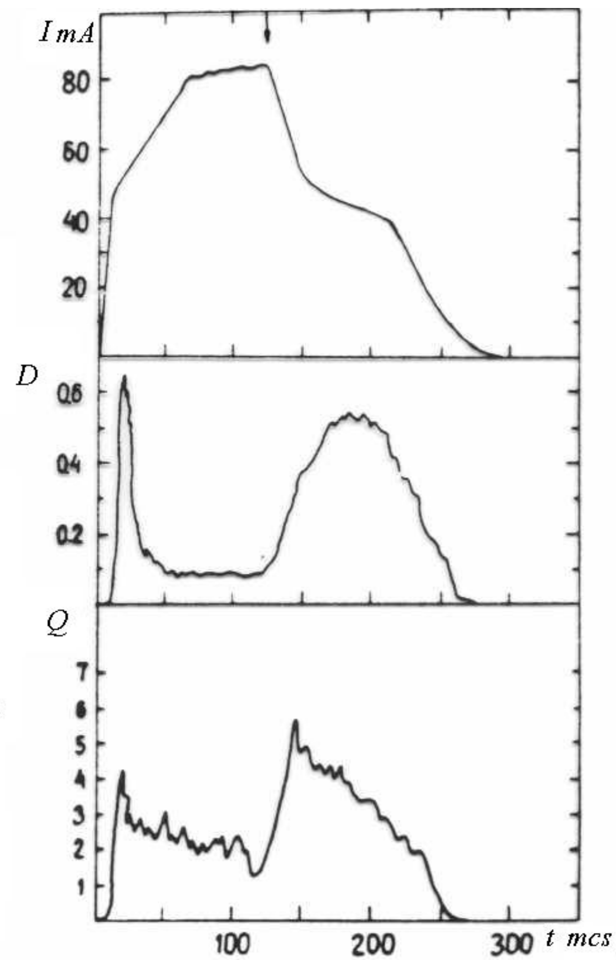


Beam accumulation with a plasma generator

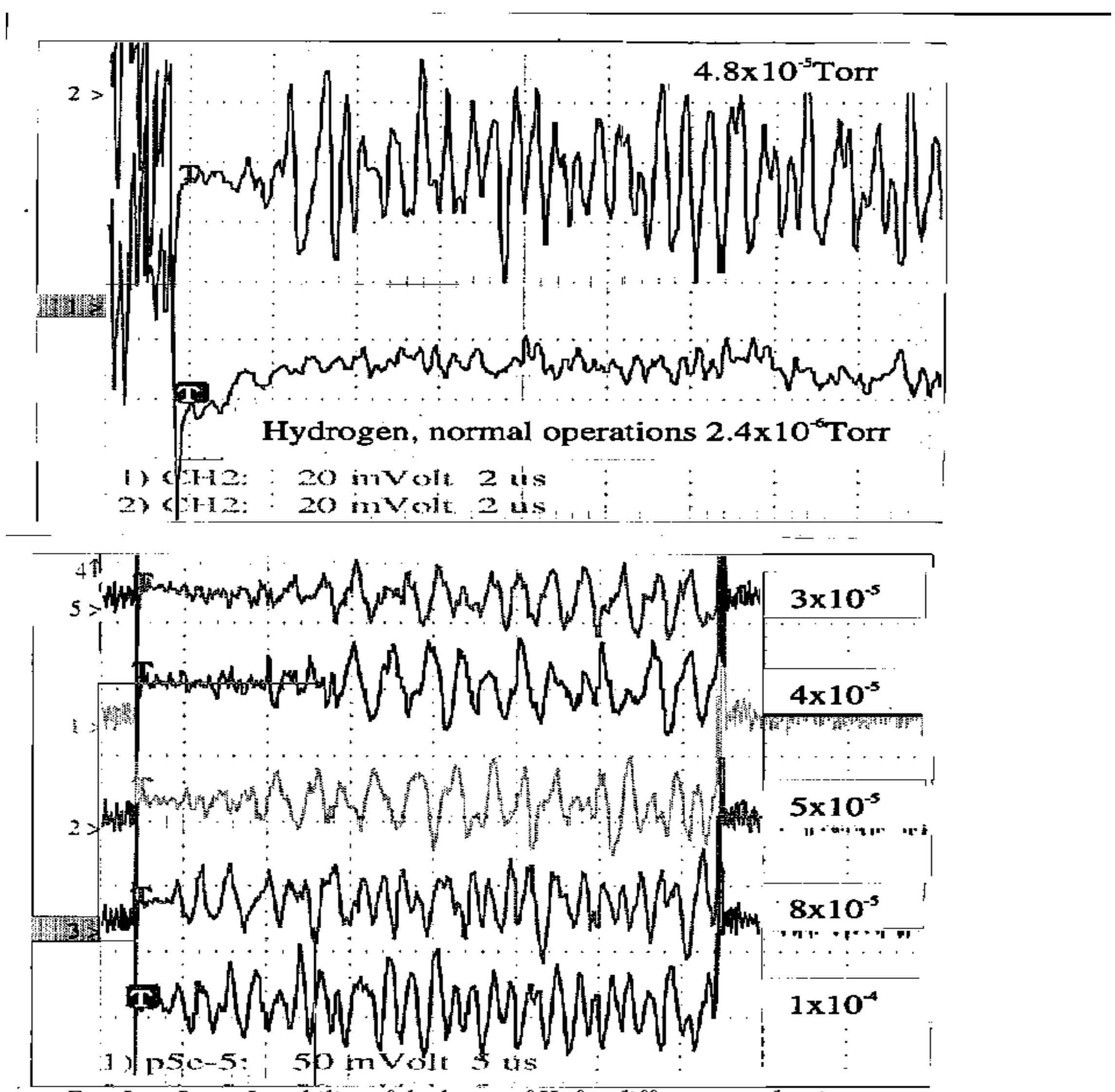
on



off



Fast Ion-beam instability of H- beam in FNAL Linac



Fast Ion- Beam Instability of the beam of H⁻ for different gas density

BPM

Signals

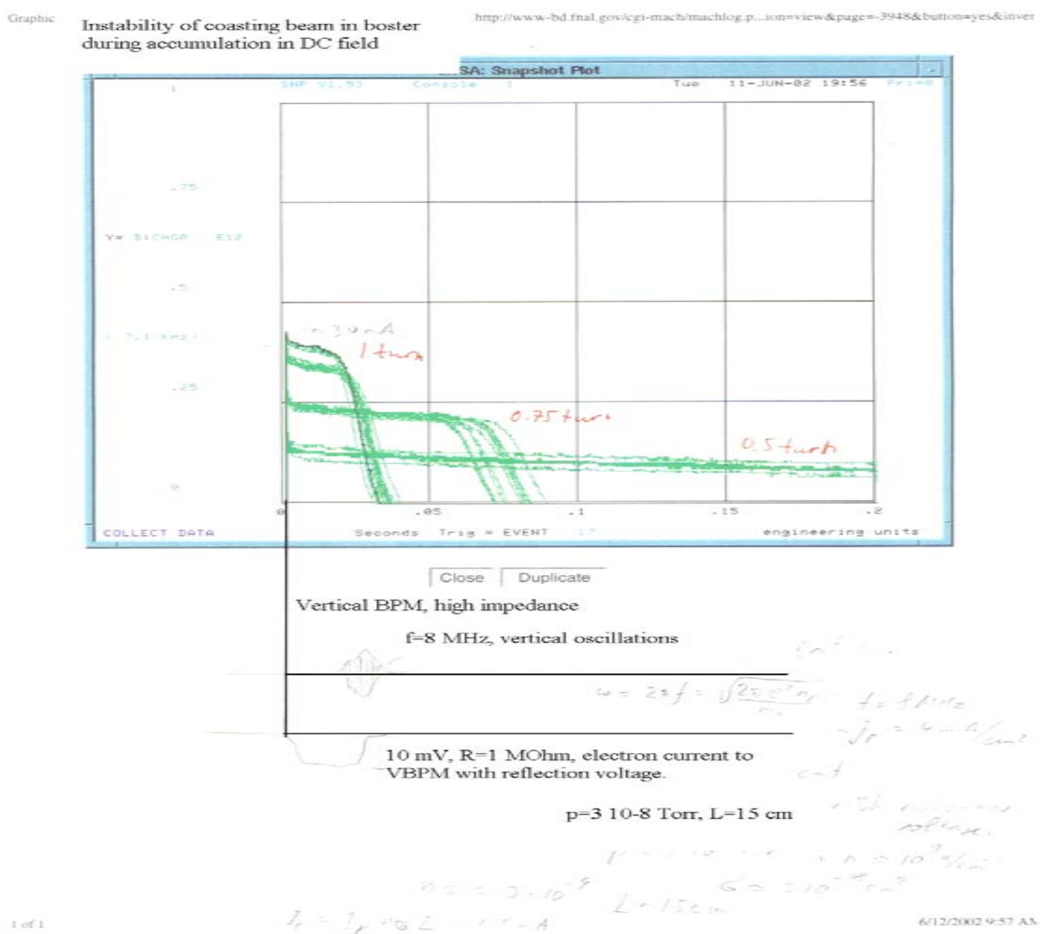
After

Preinjector

0.75 MeV

50mA

Transverse instability in FNAL Booster, DC B, Coasting beam. Injection 400MeV, 45 mA.



Secondary electron generation in the FERMILAB booster, normal acceleration

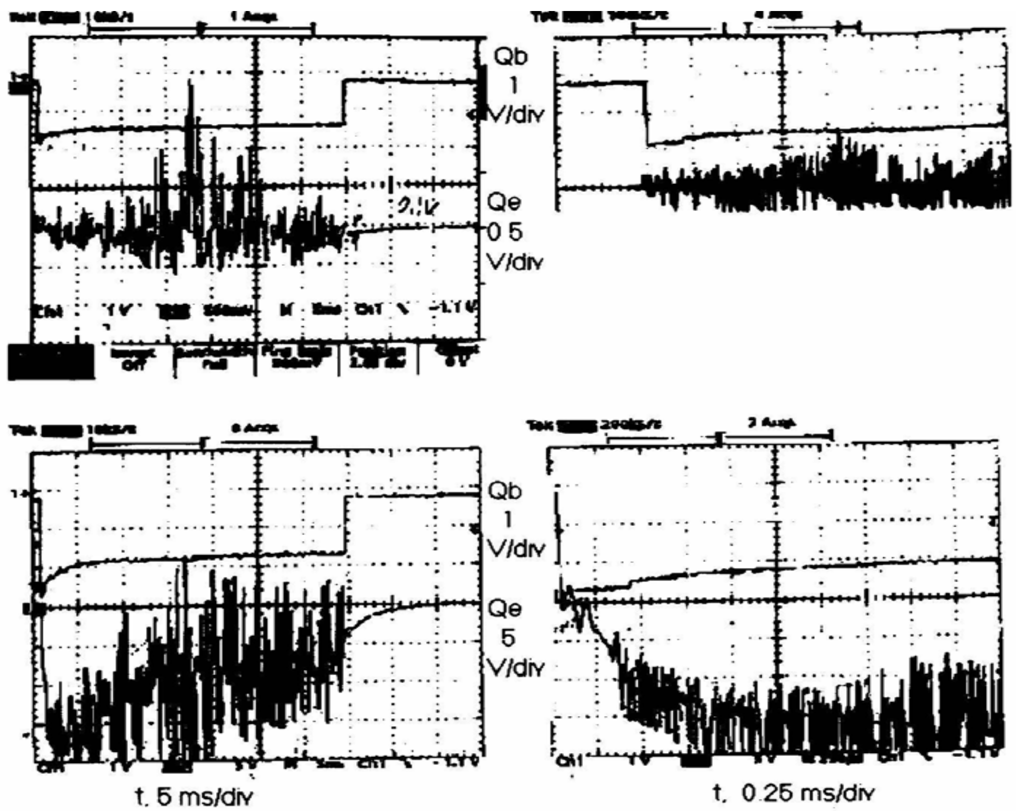
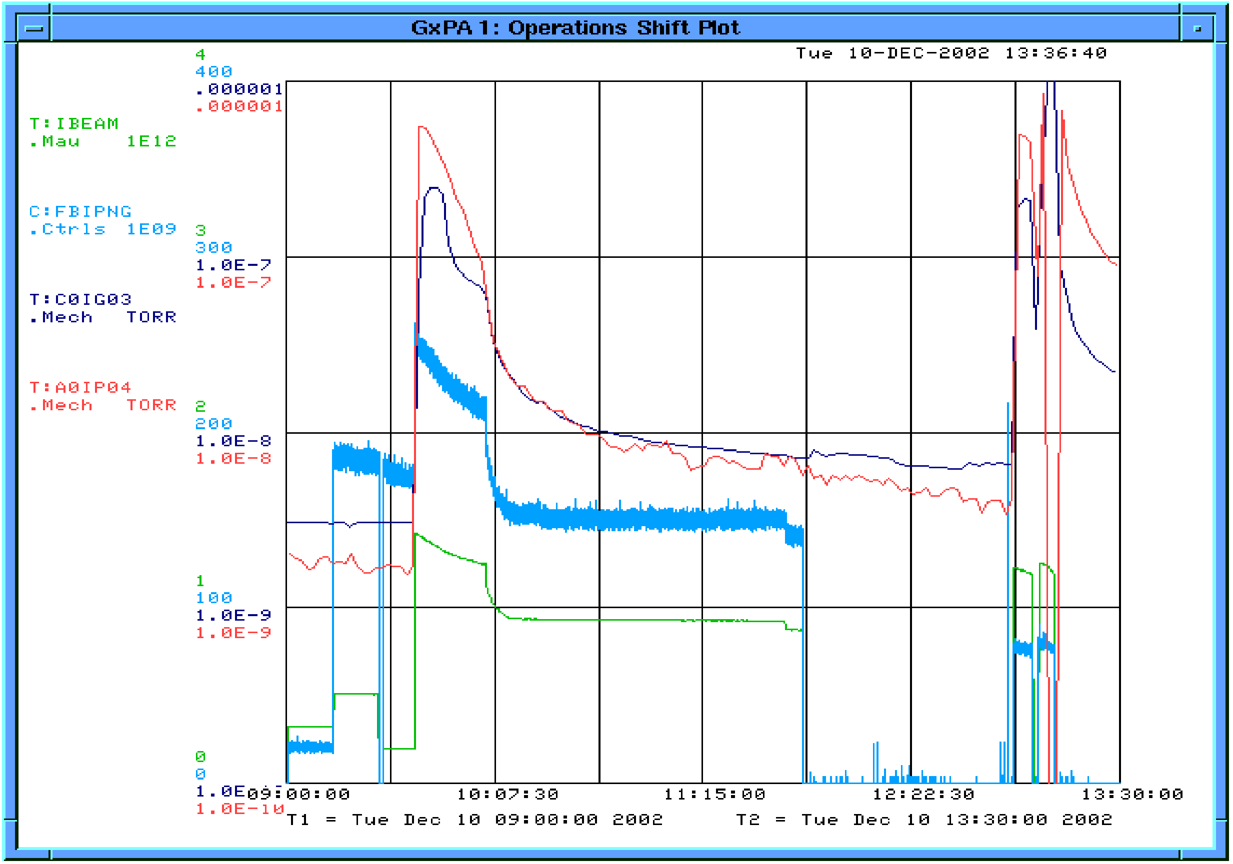


Fig. 1.Secondary electron formation in proton beam of booster
For different proton beam intensity Qb. Calibration 2E12p/V.
1 Channel: Proton beam intensity;
2 Channel: signal from reflecting plate of Ionization profile monitor (IPM). R= 1 Mohm.

Observation of anomaly in secondary electron generation in the FERMILAB Booster

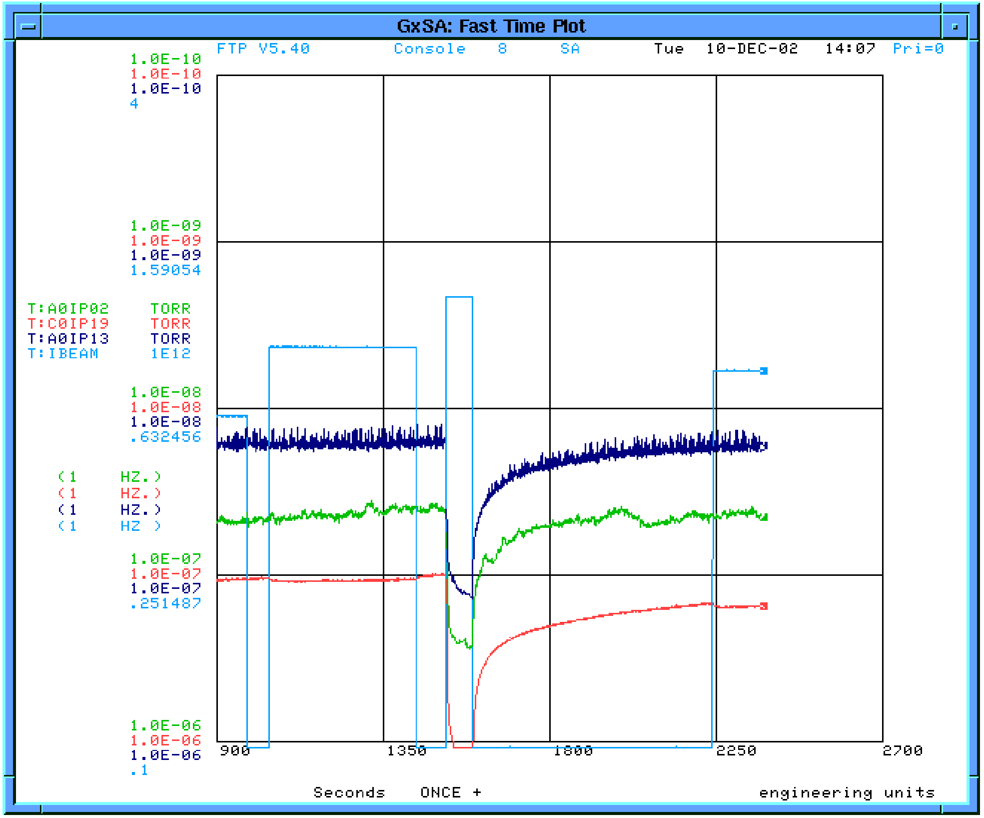
- Observation of secondary particles in the booster proton beam are presented in the Booster E-Log at 04/06/01 .
- Reflecting plate of the Vertical Ionization Profile Monitor (VIPM) was connected to the 1 MOhm input of oscilloscope (Channel 2).
- To channel 1 is connected a signal of proton beam Charge monitor Qb, with calibration of 2 E12 p/V.
- Oscilloscope tracks of the proton beam intensity Qb (uper track) and current of secondary particles (electrons) Qe (bottom track) are shown in Fig. 1 in time scale 5 ms/div (left) and 0.25 ms/ div (right).
- The voltage on MCP plate is Vmcp=-200 V.
- It was observed strong RF signal induced by proton beam with a gap (one long bunch). For intensity of proton beam Qb< 4E12 p electron current to the VIPM plate is low (Qe< 0.1 V~ 1E-7 A) as corresponded to electron production by residual gas ionization by proton beam.
- For higher proton beam intensity (Qb> 4E12p) the electron current to the VIPM plate increase significantly up to Qe=15 V~ 15 E-6 A as shown in the bottom oscillogramms. This current is much greater of electron current produced by simple residual gas ionization. This observation present an evidence of formation of high density of secondary particles in high intense proton beam in the booster, as in Los Alamos PSR and other high intense rings.
- Intense formation of secondary particles is important for the beam behavior and should be taken into account in the computer simulation.

Instability in the Tevatron



electron cloud instability in Tevatron, FNAL.
Change of vacuum and beam loss for diccerent beam intensity(green, blu).

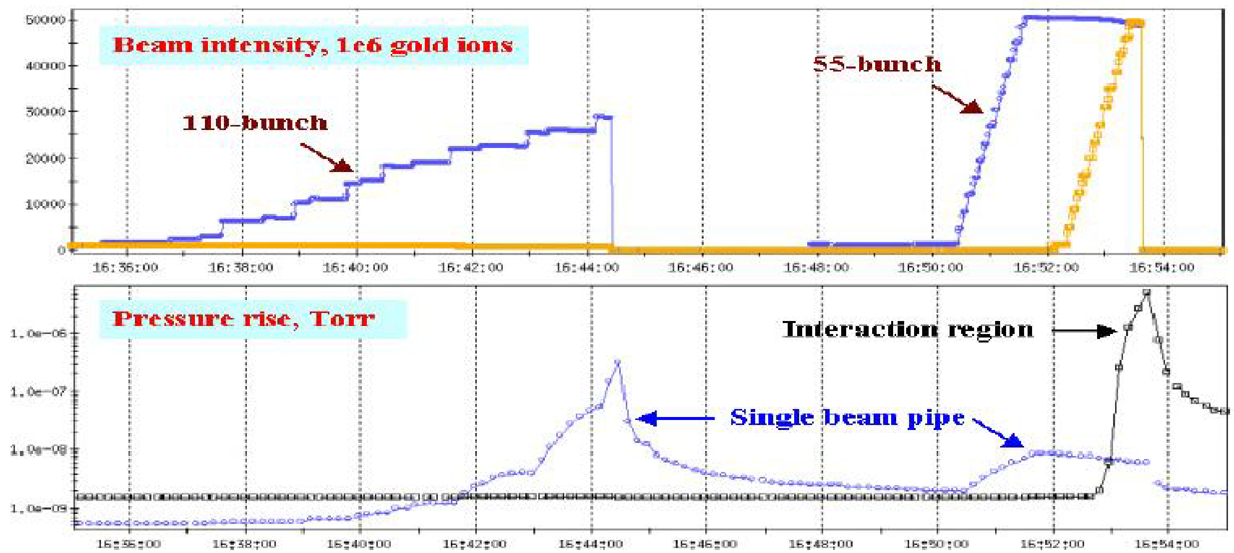
Instability in Tevatron



e-p instability in tevatrom. Change of vacuum for different beam intensity.

Instability in RHIC, from PAC03

Pressure Rise at Injection, I

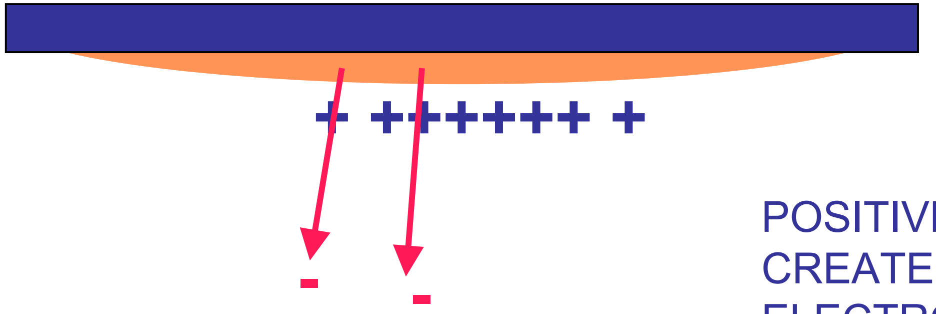


- For gold beam 55-bunch injection with bunch intensity of 0.9e9 (design 1e9), the pressure rise at IR12 reached 1e-5 Torr, valve closed, and beam dumped.
- Pressure rise is very sensitive to bunch spacing, for 110-bunch fill, bunch spacing reduced from 216 ns to 108 ns, the pressure rise at single beam straight sections was much higher than 55-bunch mode.

DEPOSITS

Cold emission of electrons from electrodes with dielectric films

CATHODE DEPOSITS INDUCE DISCHARGES: cold emission



POSITIVE IONS ACCUMULATION CREATES HIGH DIPOLE FIELD, INDUCING ELECTRON EXTRACTION (MALTER EFFECT) or sparks

Instrumentation for observation and damping of e-p instability

- 1. Observation of plasma (electrons) generation and correlation with an instability development. Any insulated clearing electrodes could be used for detection of sufficient increase of the electron density. More sophisticated diagnostics (from ANL) is used for this application in the LANL PSR. These electrodes in different location could be used for observation of distribution of the electron generation.
- 2. For determination an importance compensating particles it is possible to use a controlled triggering a surface breakdown by high voltage pulse on the beam pipe wall or initiation **unipolar arc**. Any high voltage feedthrough could be used for triggering of controlled discharge. Could this break down initiate an instability?
- 3. For suppression of plasma production could be used an improving of surface properties around the proton beam. Cleaning of the surface from a dust and insulating films for decrease a probability of the arc discharge triggering. Deposition of the films with a low secondary emission as TiN, NEG. Transparent mesh near the wall could be used for decrease an efficient secondary electron emission and suppression of the multipactor discharge. Biased electrodes could be used for suppressing of the multipactor discharge, as in a high voltage RF cavity.
- 4. Diagnostics of the circulating beam oscillation by fast (magnetic) beam position monitors (**BPM).**
- 5. Local beam loss monitor with fast time resolution. Fast scentillator, pin diodes.
- 6. Transverse beam instability is sensitive to the RF voltage. Increase of the RF voltage is increase a delay time for instability development and smaller part of the beam is involved in the unstable oscillation development.
- 7. Instability sensitive to sextuple and octupole component of magnetic field, chromaticity (Landau Damping), …

Electron generation and suppression

- Gas ionization by beam and by secondary electrons.
- Photoemission excited by SR.
- Secondary emission, RF multipactor.
- Cold emission; Malter effect; Unipolar arc discharge (explosion emission). Artificial triggering of arc.
- Suppression:
- 1-clearind electrodes; Ultra high vacuum.
- Gaps between bunches.
- Low SEY coating: TiN, NEG.
- Transverse magnetic field.
- Arc resistant material

Conclusion

- Experimental dates from small scale rings can be used for verification of computer simulation.
- Stabilization of space charge compensated proton beam with a high intensity has been observed.
- It is useful to use low energy proton ring for investigation e-p instability.